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SEA WATER INSTRUMENTED MANNEQUIN (SWIM) PRELIMINARY EXPERIMENTS

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SEA WATER INSTRUMENTED MANNEQUIN (SWIM)

PRELIMINARY EXPERIMENTS

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September 1999

This report reflects the views of the authors and not necessarily those of the Transportation Development Centre.

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16. Abstract

This report summarizes a series of exploratory experiments addressing the buoyant motion of the sea water instrumented mannequin (SWIM) in still water and in waves. The exploratory experiments were conducted at the Institute for Marine Dynamics, Towing Tank, in St. John's, Newfoundland, from 22 February to 7 March 1999. The aim was to collect experimental data on the complete SWIM that may be used in the validation of the water forces analysis capability (WAFAC) mathematical model.

The exploratory tests identified problems with the data acquisition system (DAS) and with the SWIM, although some general agreement between SWIM and WAFAC was found. Repairs to the SWIM and adjustment of the DAS are required before pursuing more validation experiments.

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16. Résumé

Ce rapport résume une série d'expériences exploratoires touchant le comportement dynamique d'un mannequin instrumenté désigné SWIM (pour *sea water instrumented mannequin*) en eau calme et dans les vagues. Ces expériences ont eu lieu dans le bassin des carènes de l'Institut de dynamique marine, à St. John's, Terre-Neuve, du 22 février au 7 mars 1999. Le but était de recueillir des données d'essais afin de valider le modèle mathématique d'analyse des forces hydrauliques (WAFAC, pour *water forces analysis capability*).

Les essais ont mis au jour des lacunes touchant à la fois le système d'acquisition des données et le mannequin. Malgré cela, les résultats des essais concordent, de façon générale, avec les prédictions du programme WAFAC. Il faudra réparer le SWIM et rectifier le dispositif de saisie des données avant de poursuivre les essais de validation.

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Thanks are expressed to Gilles Gareau of TC, André Taschereau of the Transportation Development Centre (TDC), Bert Macesker and Robert Desruisseau from the USCG Research and Development Centre and Tariq Shams from Gesac for their advice and assistance in planning and performing the experiments. Also, special thanks are extended to the Open Water Testing Facility supervisor, Spence Butt, and all his staff.

EXECUTIVE SUMMARY

This report summarizes a series of exploratory experiments addressing the buoyant motion of the sea water instrumented mannequin (SWIM) in still water and in waves, undertaken by the Institute for Marine Dynamics of the National Research Council Canada, for the Transportation Development Centre, Transport Canada. The aim was to collect experimental data on the complete SWIM for use in the validation of the water forces analysis capability (WAFAC) mathematical model.

The study included the following:

- Bottom release tests – SWIM was released below the water surface and its motions tracked during ascent.

- Tests in waves – the mannequin's motion was tracked in regular waves of 0.25 m in height and different frequencies.

- Push-glide tests – the gliding motion of SWIM was tracked after being pushed along the water surface and floating with its longitudinal plane parallel to it.

Prior to these tests the mannequin's centre of gravity and buoyancy were determined, along with its hydrodynamic drag.

The buoyancy of the mannequin was determined for two configurations by immersing it into, and lifting it out of, the water. The first configuration had the arms up in a T-fashion, while the second had the arms down along the torso.

The centres of gravity and buoyancy were determined for two configurations, vertical and bent at the waist (sitting), while the drag tests were performed for the forward and reverse directions and for four configurations (horizontal; vertical, face forward; vertical, right should forward; and bent at the waist, sitting, face forward).

The exploratory tests identified problems with the data acquisition system (DAS) and with the SWIM, although some general agreement between SWIM and WAFAC was found. Repairs to the SWIM and adjustment of the DAS are required before pursuing more validation experiments.

SOMMAIRE

Ce rapport résume une série d'expériences exploratoires touchant le comportement dynamique d'un mannequin instrumenté désigné SWIM (pour *sea water instrumented mannequin*) en eau calme et dans les vagues. Ces expériences ont été réalisées par l'Institut de dynamique marine du Conseil national de recherches du Canada, pour le compte du Centre de développement des transports de Transports Canada. Le but était de recueillir des données d'essais afin de valider le modèle mathématique d'analyse des forces hydrauliques (WAFAC, pour *water forces analysis capability*).

Voici en quoi consistaient ces expériences :

- Essais de largage – le mannequin SWIM était largué depuis une position stable sous l'eau, et on observait ses mouvements pendant la remontée.
- Essais dans la houle – le mannequin était plongé dans des vagues régulières de 0,25 m de hauteur et de différentes fréquences; ses réactions étaient enregistrées.
- Essais de poussée-glissement – on poussait le mannequin à la surface de l'eau et on observait ses réactions pendant qu'il glissait, flottant à l'horizontale.

Avant les essais, le centre de gravité et la flottabilité du mannequin étaient déterminés, de même que sa traînée hydrodynamique.

Pour déterminer la flottabilité du mannequin, on le plongeait dans l'eau pour ensuite l'en retirer. Deux configurations ont été étudiées : les bras en croix et les bras près du corps.

Le centre de gravité et la flottabilité étaient déterminés pour deux positions du mannequin : debout et assis (taille fléchie). Quant aux essais de traînée hydrodynamique, ils consistaient à tirer et pousser le mannequin, selon quatre configurations (ce qui donnait huit cas de figure) : à l'horizontale (tête ou pieds devant); à la verticale, de face (ou de dos); à la verticale, de côté (épaule droite vers l'avant, épaule gauche vers l'arrière); assis (taille fléchie), de face (ou de dos).

Les essais ont mis au jour des lacunes touchant à la fois le système d'acquisition des données et le mannequin. Malgré cela, les résultats des essais concordent, de façon générale, avec les prédictions du programme WAFAC. Il faudra réparer le SWIM et rectifier le dispositif de saisie des données avant de poursuivre les essais de validation.

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GLOSSARY

ATB	Articulated Total Body
CCG	Canadian Coast Guard
DAS	Data Acquisition System
JRPA	Joint Research Programme Agreement
IMD	Institute for Marine Dynamics
IMO	International Maritime Organization
NRC	National Research Council Canada
SOLAS	Safety of Life at Sea
SWIM	Sea Water Instrumented Mannequin
TDC	Transportation Development Centre
TT	Tow Tank
USAF	United States Air Force
USCG	United States Coast Guard
WAFAC	Water Forces Analysis Capabilities

1.0 INTRODUCTION

The U.S. Coast Guard (USCG) and Transport Canada (TC) have sponsored the development of an instrumented flotation mannequin designated as the Sea Water Instrumented Mannnequin (SWIM). They have also sponsored the development of computer software called the Water Forces Analysis Capability (WAFAC), which works with either the Articulated Total Body (ATB) program or the DYNAMAN program. Both the new mannequin and the software are intended to evaluate the performance of personal flotation devices (PFDs).

Preliminary validation of the WAFAC model was conducted in 1994 by examining the controlled translation and rotation motions of various sized ellipsoids in calm water. These simple exercises indicate that the model performs well with simple shapes.

The next step is the comparison of the WAFAC model motions with those recorded with the actual SWIM mannequin in both still water and waves.

The Institute for Marine Dynamics (IMD) was contracted to conduct a series of exploratory experiments addressing the SWIM buoyant motion in still water and in waves. The aim of the tests was to collect experimental data on the complete SWIM mannequin that may be used in the validation of WAFAC mathematical model.

Experiments ranged from simple depth release tests, through push-glide tests, to tests in 0.25 metre waves. The Institute also conducted separate experiments to determine the mannequin's centres of gravity and buoyancy and its hydrodynamic drag. These additional experiments were performed for the mannequin in vertical and bent at the waist (sitting) configurations.

2.0 SCOPE OF WORK

The present effort concentrated on the acquisition of experimental data on SWIM buoyant motion in still water and in waves to validate WAFAC mathematical model.

Phase I Development of detailed work plan, activity schedule and cost estimates.

Phase II Design and manufacturing of testing apparatus. Preparation of the site (Tow Tank) to accommodate deployment and camera towers.

Phase III Mannequin set-up and calibration. Hydrodynamic drag experiments on the mannequin in the forward and reverse directions and for different configurations, i.e. vertical, and bent at the waist (sitting). Mannequin's centres of gravity and buoyancy experiments.

Phase IV Bottom release tests in still water, tests in 0.25 m waves, and push-glide tests.

The experiments documented in this report were conducted at the Institute for Marine Dynamics, Tow Tank, in St. John's, Newfoundland, from 22 February to 7 March 1999.

3.0 SEA WATER INSTRUMENTED MANNEQUIN (SWIM)

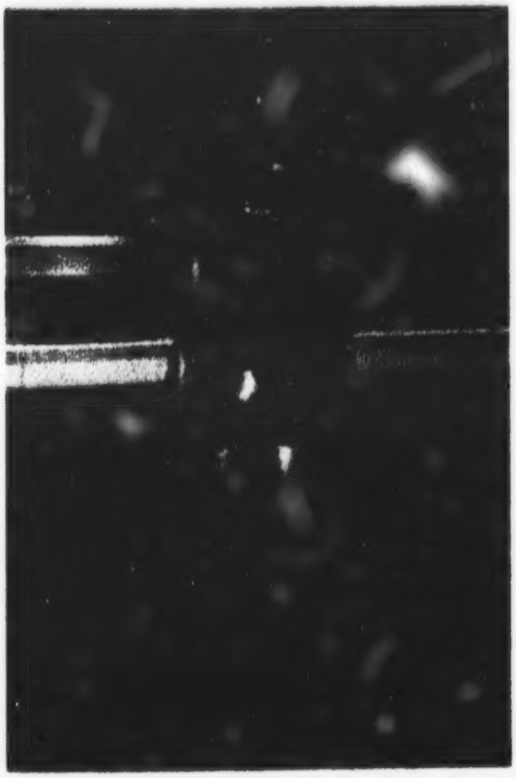
The SWIM is made of numerous components and subsystems and is constructed from combinations of 316 stainless steel, UHMW plastic, titanium and Delrin. The mannequin's skin is made from vinyl, molded to a thickness of approximately 3 mm. The non-structural parts of the mannequin's segments are made of closed cell foam, except the hip skin pieces, which are made of open cell foam. This type of foam is used in this area to allow compression for movement. The dimensions of the mannequin correspond to a fiftieth percentile adult male in a normal standing position. The mannequin has flexibility at the major body joints, allowing it to behave in a similar manner to a human. Figures 3.1 and 3.2 show the mannequin with and without the neoprene chest vest, prior to testing.

Figure 3.1 – Salt Water Instrumented Mannequin (SWIM)

The SWIM as delivered to the Institute had a height of 1.743 m and a dry weight in air of 69.0 kg. This weight included a neoprene vest weighing 2.72 kg, and used to provide the SWIM with extra buoyancy. The mannequin's buoyancy can be further varied by adding or removing weights from the thorax and the different segments (i.e. upper/lower arms, upper/lower legs). Adjustments can be made at the joints in order to increase or decrease motion. The mannequin may be lifted from four different locations, namely, the top of the head, the shoulders, the knees and the bottom–pelvic region on either side. At the Institute, all the lifting was done from the top of the head.

The SWIM has five different types of sensors, totaling 31. The mannequin's joint rotations at the neck, spine and limbs are measured by 21 potentiometers. The accelerations are measured by one tri-axial accelerometer, while the body attitude with respect to a stationary reference frame is measured with a bi-axial tilt sensor for the pitch and roll and a direction compass for the yaw angle. Four piezoresistive pressure sensors measure the difference in hydrostatic pressure. The thorax cavity contains the data acquisition system (DAS), the batteries, a receiver board and a humidity sensor. The DAS on/off function is remotely operated with the receiver mounted in a box in the thorax, with the antenna mounted on the head.

Figure 3.2 –SWIM with Neoprene Chest Vest Added



4.0 EXPERIMENTAL STUDY

The still water and wave experiments were conducted in the Tow Tank (TT). Mannequin set-up and calibration took place in the staging area of the TT. Experimental determination of the centre of gravity (CG) took place in the model preparation area. The different components of the testing apparatus, i.e. release mechanisms, frames, etc., were designed and manufactured at the Institute by Design and Fabrication personnel.

4.1 Experimental Set-up

The different types of experiments conducted with the SWIM required more than one location and more than one individual set-up. The following paragraphs describe each experiment type set-up.

- Centre of Gravity (CG) – The centre of gravity of the SWIM for the vertical and the bent at the waist (sitting) configurations was measured by swinging the mannequin in air on the Institute's lightweight swinging frame. The frame components include an aluminum box beam supported by knife edges at the ends. The knife edges rest on hardened steel pads mounted on top of a steel structure attached to the lab floor. Normally, this frame is used in the estimation of the CG of small offshore structure models. The shape of SWIM required some modifications to the frame itself. Two aluminum angle bars, 0.60 m apart, were connected to the box beam frame. From these bars, four ½" threaded rods, 0.5 m long were bolted to the aluminum angle at the top and to a plywood platform at the bottom. The plywood platform supporting the mannequin measured 0.75x1.25 m square and was ¾" thick. The restoring moment and mass moment of inertia of the frame were determined.

The vertical centre of gravity (VCG) for the vertical configuration was calculated by placing the mannequin, outfitted with its neoprene jacket, flat on its back on the plywood platform and adjusting the mannequin's position until an inclinometer mounted on the box beam read approximately 0° inclination from the horizontal. The final adjustment was provided by a five-kilogram weight. When the inclinometer reading registered $0^\circ \pm 0.01^\circ$ inclination, a reference mark was made on the mannequin with respect to the knife edges plane and the location of the weight with respect to the same plane.

At this stage the process to determine the longitudinal centre of gravity (LCG) (i.e. back to front direction) was started. The restoring moment and mass moment of inertia of the frame, mannequin and weight were determined and the LCG estimated.

The mannequin is assumed to be transversely symmetric (i.e. right to left direction) and no test is required to establish the transverse centre of gravity (TCG).

The set-up for the estimation of the bent at the waist (sitting) configuration centres of gravity is similar to the one described above.

- Buoyancy Test – A simple experiment was devised to determine the SWIM buoyancy at different levels of immersion in water. The test was conducted in the trim dock area of the Tow Tank and used the facility's DAS to record the values. The mannequin was hung from the crane through a load cell. A five-kilogram weight was hung from the mannequin's feet. A total of nine different levels of immersion were established for the mannequin for a lowering into, and lifting out of the water surface. The levels of submergence were as follows: (1) air, (2) five-kilogram submerged, (3) up to ankle bolt, (4) up to knee bolt, (5) up to femur bolt, (6) up to top of pelvis, (7) up to arm pits, (8) up to bottom of neck and (9) head totally submerged.

The out of the water submergence levels were the same as those reported above, but run in opposite direction (i.e. start with the mannequin submerged until it was clear of the water surface).

The lowering and raising of the mannequin from the water surface was performed for two different configurations of the arms. The first configuration had the arms up in a T-fashion, while the second had the arms down along the torso.

- Centre of Buoyancy – The centre of buoyancy (CB) of the SWIM for the vertical and the bent at the waist (sitting) configurations was measured by immersing the mannequin three metres under the water surface and pulling from four different locations, namely, the ankles, the knees, the shoulders and the head. The mannequin's pitch sensor was used to measure the different attitudes caused by the different pull points. These data were then used in conjunction with the centre of gravity to determine the position of the vertical CB. The longitudinal and transverse CB is assumed to be in line with the CG.

- Hydrodynamic Drag Tests – In preparation for these tests a frame to which the mannequin could be attached was designed and built. The hydrodynamic drag of the frame alone was submerged to a predetermined depth and measured in the forward and reverse direction. The hydrodynamic drag of the mannequin and frame was measured for four different configurations, horizontal, vertical face forward, vertical right shoulder forward and bent at the waist (sitting) face forward. Velocities ranged from 0.1 to 1.0 m/s for the horizontal configuration and 0.1 to 0.5 m/s for the other configurations. The hydrodynamic drag of the mannequin was calculated by subtracting the drag of the frame from the total drag of the system. Projected areas for the mannequin in the

different configurations were determined from the SWIM drawings, Ref 1, and the hydrodynamic coefficient calculated.

- Bottom Release Tests – In preparation for this type of experiment, a spring-loaded release mechanism was designed and manufactured and attached to a styrofoam float. The release-mechanism-float combination was attached to a horizontal beam supported by an underwater tower and used to pull the SWIM to the release depth. The beam position could be adjusted up or down to achieve the required release depth. A braided rope attached to the underside of the styrofoam float passed through a hole in the horizontal beam, through a pulley at the base of the tower and up to the side of the tank. The SWIM was hooked onto the release mechanism at the water surface and pulled from the side of the tank to the required release depth. Release of the mannequin was initiated by pulling on a string tied to the pin of the release mechanism. Vertical horizontal and bent at the waist configurations were used in this type of test. For the vertical configuration the mannequin was released from depths of 7, 5, 4 and 3 m (nominal), while for the horizontal and bent at the waist configurations the mannequin was release from a nominal depth of 3 m.

- Tests in Waves – In preparation for these tests, the joints of the mannequin were locked in either the near vertical or bent at the waist configurations. Reflective markers mounted on lightweight rods were attached to its head, and the SWIM floated to the centre of the tow tank. Regular waves 0.25 m high and with frequencies of 0.3, 0.5 and 0.7 Hz were run. All the tests were run for the mannequin with 1.8 kg of buoyancy.

- Push-Glide Tests – A specially built frame was mounted to the towing carriage to hold the SWIM horizontal at the water surface. The mannequin was towed from the shoulders by lightweight rope looped over the pins of the frame. The feet of the SWIM were held in place during acceleration. After reaching the appropriate speed the carriage was stopped abruptly and the feet released at the same time. The SWIM glided forward freeing itself from the towing pins. The optical tracking system was not activated for these types of test. The mannequin, with 1.8 kg of buoyancy was attached to the frame horizontally, face down and head forward. The SWIM did not achieve gliding motion for any the speeds tested.

4.2 Test Programme and Procedures

In preparation for the SWIM preliminary experiments the buoyancy characteristics, the centres of gravity and buoyancy and the drag coefficient of the mannequin were determined. Bottom release, motions in regular waves and push-glide tests were conducted for the mannequin. Vertical, horizontal and bent at the waist configurations were used in the bottom release tests while only the horizontal configuration was used for the push-glide tests. The motions in waves were assessed for the vertical and bent at the waist configurations in three regular waves of 0.25 m height and frequencies of 0.3, 0.5 and 0.7 Hz. The test matrix is summarized in Table 4.1.

Table 4.1 – Test Matrix

	B (N)	Centre Grav. (m)		Centre Buoy (m)		Drag (N)			Bot. Rel. (m)			Wave Freq. (Hz)			Push Vel. (m/s)	
	Vert.	Vert	Bent	Vert	Bent	Vert	Hor.	Bent	3	4	5	0.3	0.5	0.7	0.50	1.00
Buoyancy	*															
Centre Grav.		*	*													
Centre Buoy.				*	*											
Drag						*	*	*								
Bot. Release									*	*	*					
Mot. in Waves												*	*	*		
Push-Glide															*	*

Figure 4.1 – Set-up for Buoyancy Tests

The procedures employed in the experiments identified in the test matrix are described below.

BUOYANCY TEST

i. Calibrate a 1112 N (250 lb.) S-type load-cell and configure the towing carriage data acquisition system to continuous read-out.

ii. Configure the mannequin to the arms up in T-fashion or down along the torso and lock all joints. For the T-fashion configuration provide additional support to the arms by means of rope, Figure 4.1.

iii. Attach the mannequin and load cell to the crane hook and lift. Attach a 5.0 kg weight to the ankles of the mannequin.

iv. Lift mannequin, load cell and weight over the trim dock, establish the levels of immersion required and start recording the weights.

v. Proceed to lower the SWIM through the following nine different levels: air, 5.0 kg submerged, up to ankle bolt, up to the knee bolt, up-to the femur bolt, up to the top of pelvis, up to the armpits, up to the bottom of the neck and totally submerged. At each level let the mannequin rest for about one minute and record the load cell reading. Figures 4.2 and 4.3 illustrate a couple of the submergence levels.

vi. Start the raising of the mannequin from the water by stopping at the different levels and time stated in (v).

vii. Reconfigure the mannequin to the arms along the torso, lock joints and follow steps (iii to vi).

Figure 4.2 – Buoyancy Tests, Up to Femur Immersion Level

Figure 4.3 – Buoyancy Tests, Up to Armpits Immersion Level

Centre of Gravity Test

i. Establish the restoring moment and mass moment of inertia for the modified swing frame. Measure the change in angle caused by applying a load at a known distance from the knife edge plane and determine the frame's swinging period.

ii. Configure the SWIM to the vertical position, lock all joints and place face up on the plywood platform of the swing frame.

iii. Adjust the position of the mannequin until the inclinometer on the swing frame's box beam registers approximately 0° inclination. Make final adjustments with a 5 kg weight so that the inclinometer readings are within $0^{\circ}\pm0.01^{\circ}$ inclination.

iv. Make a reference mark on the mannequin with respect to the knife edges plane and measure the 5 kg-weight position with reference to the same plane. Calculation of the VCG can now be made.

v. Establish the restoring moment and mass moment of inertia for the modified swing frame mannequin and 5 kg weight. Measure the changes in inclination angles resulting from an applied load and determine the system swinging period. Figures 4.4 and 4.5 show the mannequin resting on the plywood frame of the swinging frame.

Figure 4.4 – Centre of Gravity Vertical Configuration, View 1

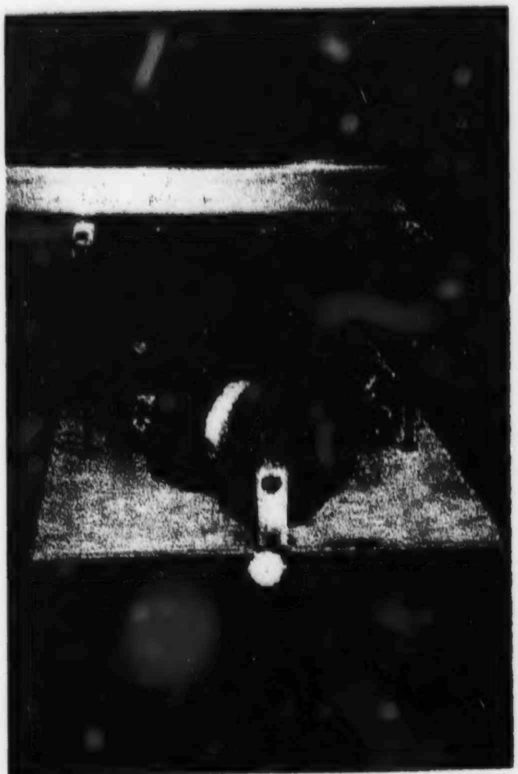


Figure 4.5 – Centre of Gravity Vertical Configuration, View 2

vi. Remove mannequin from the platform and reconfigure for the bent at the waist configuration. Lock all the joints and position the mannequin, face towards the aluminum box beam, on the plywood platform of the swing frame.

vii. For estimation of the vertical and longitudinal CG for the bent at the waist configuration, follow steps (iii to vi). Figures 4.6 and 4.7 illustrate the mannequin in the sitting configuration in the swinging frame.

Figure 4.6 – Centre of Gravity Bent at the Waist Configuration, View 1

Figure 4.7 – Centre of Gravity Bent at the Waist Configuration, View 2

Centre of Buoyancy Test

i. Configure the SWIM to the vertical position, lock all joints, activate the DAS and pull from the ankles to an immersion depth of 3 m and record the attitude of the mannequin with respect to the vertical plane.

ii. With all the joints locked, pull point to the knees, immerse to 3 m and record the mannequin attitude with respect to the vertical plane.

iii. Repeat (ii) for the chest and head pull points. Record the data with the SWIM DAS. Calculate the centre of buoyancy for the mannequin.

iv. Change the SWIM to the bent at the waist configuration and repeat steps (ii to iii).

Hydrodynamic Drag Test

i. Calibrate the load cells of the dynamometer.

ii. Attach the drag frame to the dynamometer installed on the towing carriage.

iii. Determine the frame drag in the forward and reverse directions for different depths and speeds.

iv. Configure the mannequin to the vertical position with the arms along the torso and lock all the joints. Prepare the mannequin for the first of four configurations, i.e. vertical right shoulder forward.

v. Attach the mannequin to the frame and lower to the proper depth. Figures 4.8 and 4.9 illustrate the process.

Figure 4.8 – Hydrodynamic Drag Test: Vertical Right Shoulder Forward, Position 1

Figure 4.9 – Hydrodynamic Drag Test: Vertical Right Shoulder Forward, Position 2

vi. Run the carriage in the forward and reverse directions for 0.1 to 0.5 m/s. The speed limit is imposed by the strain imparted on the mannequin joints. Record the drag data for the mannequin and frame with the towing carriage DAS. Calculate the drag of the mannequin alone.

vii. Determine the mannequin's projected area for the configuration and calculate the respective drag coefficient.

viii. Change configuration and repeat steps (iii to vii). Figures 4.10 to 4.12 illustrate the drag tests for the other configurations.

Note: For the horizontal configuration the range of speed was increased to 1.0 m/s.

Figure 4.10 – Hydrodynamic Drag Test: Vertical, Face Forward

Figure 4.11 – Hydrodynamic Drag Test: Bent at the Waist, Face Forward

Figure 4.12 – Hydrodynamic Drag Test: Horizontal, Head Forward, Face Up

Bottom Release Test

i. Transport the mannequin from the staging area at the end of the TT to half way on the side of the TT.

ii. Install qualisys markers on the mannequin. Install the tower and adjustable horizontal beam. Attach the release mechanism to the styrofoam float. Attach a lightweight rope to the underside of the styrofoam float, pass it through a hole on the horizontal beam through a pulley a the base of the tower and up the side of the tank. Also attach a lightweight string to the spring of the release mechanism, pass the string trough a pulley mounted on the tower and bring to the side of the tank.

iii. Attach a bridle to the mannequin at the ankle level.

iv. Adjust the beam the required depth.

v. Connect the mannequin to the release mechanism and activate the DAS system.

vi. Pull the rope until the styrofoam float is touching the horizontal beam and turn the qualisys system on.

vii. Pull the string attached to the release mechanism to release the mannequin.

viii. Repeat at the same depth and configuration three times. After the third run download the DAS data from the mannequin to a PC.

ix. Change the water depth while maintaining the same configuration. Repeat steps (v to viii).

x. Change configuration and repeat steps (iv to ix).

Motions in waves Test

i. Install wave probe off the towing carriage. Install qualisys "tree" on the head of the mannequin.

ii. Configure the mannequin to the vertical position, lock all joints and lower into the water.

iii. Start the data acquisition system on the SWIM and towing carriage and after a few seconds start the wave maker.

iv. Collect wave and motion data for approximately 150 seconds.

v. Repeat steps (iii and iv) for the other wave frequencies.

vi. Lift SWIM to the sided of the tank, reconfigure to the bent at the waist configuration, lock all joints and lower in to the tank.

vii. Repeat steps (iii to v).

Figures 4.13 to 4.17 illustrate the mannequin fitted with the qualisys "tree" mounted on the top of the head for the vertical and sitting configurations prior to tests in waves.

Figure 4.13 - Motion in Waves, View 1

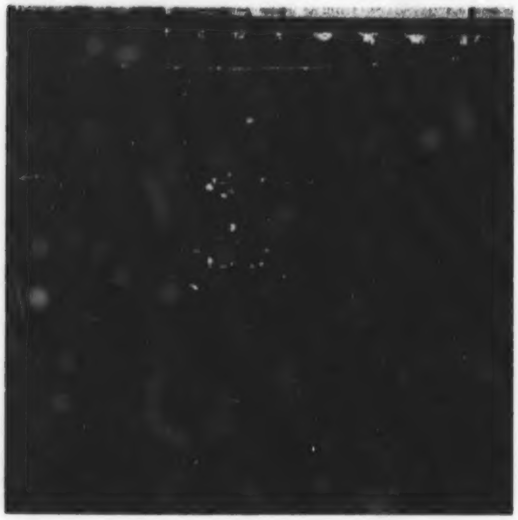


Figure 4.14 - Motion in Waves, View 2

Figure 4.15 - Motion in Waves, View 3

Figure 4.16 - Motion in Waves, View 4

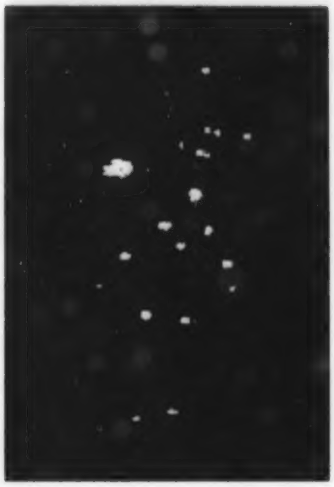
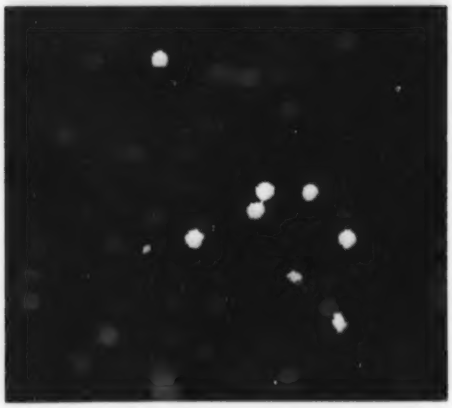


Figure 4.17 - Motion in Waves, View 5



Push-glide Test

i. Install the push-glide frame to the towing carriage. Configure the mannequin to the vertical configuration and lock all joints.

ii. Attach the SWIM to the frame, facing the bottom of the tank. Attach string to the feet of the mannequin in order to maintain its position parallel to the water surface.

iii. Accelerate the carriage to 1.0 m/s and then stop. At the time the carriage is stopped release the string freeing the feet.

iv. Observe the mannequin as it frees itself from the frame and glides.

v. Repeat steps (iii and iv) for other speeds.

Note: The optical tracking system Qualisys™ was not used during these tests.

Figures 4.18 to 4.21 illustrate the push-glide frame and the mannequin prior to and during testing.

Figure 4.18 - Push-Glide Tests: Frame

Figure 4.19 - Push-Glide Tests, View 1

Figure 4.20 - Push-Glide Tests, View 2

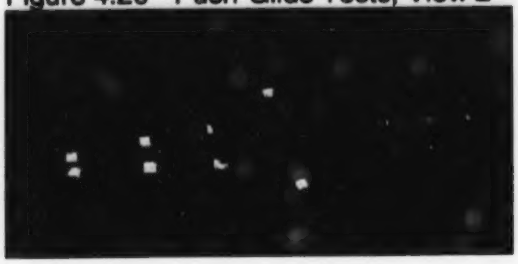


Figure 4.21 - Push-Glide Tests, View 3

4.3 Data Analysis and Techniques

The measurements of the positions of the SWIM during bottom release and motion in waves were acquired by the optical tracking system, Qualisys™, video imaging and the mannequin's own data acquisition system. This report deals with data from Qualisys and video imaging. Push-glide tests were conducted, but only visual observations were made and no data were collected.

Qualisys™ data for the bottom release tests were sampled at 50 Hz and stored for post processing into vertical motion data, while data from the motion in waves were immediately processed and converted into X-Y-Z data. Video imaging data, followed by digital processing of the still images were collected to obtain the vertical position of the mannequin for the bottom release tests and were used as a back-up to the Qualisys™ system. The mannequin's onboard data acquisition system collected data from a number of sensors for all the tests. Table 4.2 summarizes the type of analysis used on the various tests.

Table 4.2 Summary of Data Analysis Breakdown for the Different Tests

	Avg's	Time Series	Basic Stats	Resist.	ZCA	RAO's	Special Analysis
Buoyancy	*						
Centre of Gravity	*						
Centre of Buoyancy	*						
Hydro. Drag		*	*	*			1
Bottom Release		*	*				
Motion in Waves		*	*		*	*	2

Notes:
1 – Hydrodynamic Coefficients
2 – Sine_Fit: Comparison of amplitude and phase of fitted and acquired data.

The SWIM motions for the bottom release and motion in wave experiment were recorded using the Qualisys™ motion tracking system. For the bottom release tests, two video cameras in underwater housings were mounted on the underwater flow visualization towers. The mannequin was tracked using 19 reflective tape markers attached to the mannequin's skin and chest vest. The video camera signals were fed through video processors by which the positions of the tape markers were digitized at 50 Hz before being sent back to an IBM compatible computer on the side of the tank. For the motion in waves experiments the video cameras were mounted above water on the towing carriage. For these experiments the cameras tracked seven marker balls supported by lightweight rods attached to the mannequin's head.

The system's accuracy depends on the distance of the cameras from the mannequin. For the present application a displacement measurement accuracy of ±5mm was achieved. Given the different configurations used throughout the experiments and the fact that the mannequin has some flexibility, it is accepted that the position of the

tape/ball markers may have changed slightly, thus influencing the overall accuracy of the measurement.

Preliminary processing was performed to translate the tape/ball marker positions into time series of the mannequin motions using the procedure described in Reference (1). The first step was to resolve the photogrammetric equations to obtain the X, Y, Z of each tape/ball marker. These data were then transformed in a least square fit to obtain the motions of the mannequin.

The runs for which Qualisys data were not reliable, video imaging followed by digital processing of the still images were used to obtain positions. The method is accurate, however, the amount of manual work involved is considerable and the processing time increased. The cameras were mounted on the flow visualization tower just above the Qualisys cameras. The mannequin motions obtained from the video will be restricted to a single vertical plane.

The standard video consisting of 60 fields per second, with two frames merged to create a single field, which translates in a sampling rate of 30 Hz. The video camera stores time and frame number information on the tape making it possible to identify specific frames during playback. The tape was played back frame by frame and every two frames were selected. The video signal was passed through a time base correction unit, which ensured correct synchronization of the paused video frame. It was then fed into a frame grabber board installed in a personal computer. The video images were first calibrated using known positions in the plane of motion of the mannequin. A calibration frame was placed in the vertical plane of the experiments. A video frame was captured with the calibration frame in position and the calibration of the software performed.

5.0 RESULTS AND DISCUSSION

In the sections below the results of the different experiments will be summarized and the major issues discussed.

5.1 Centre of Gravity

The centre of gravity was calculated in air with the aid of the swinging frame. The coordinate system for the mannequin in the standing configuration is defined a right-handed system with the origin as illustrated in Figure 5.1. The X-axis (longitudinal) is from the heels towards the toes, the Y-axis (transverse) is from between the feet to the left foot and the Z-axis (vertical) is upwards towards the head. The coordinate system for the mannequin in the bent at the waist configuration is defined as a right-handed system with the origin as illustrated in Figure 5.1. The X-axis is from the bottom of the feet towards the torso, the Y-axis towards the right shoulder and the Z-axis upwards towards the head. Table 5.1 below summarizes the results for the longitudinal and vertical centres of gravity for two mannequin configurations, namely, vertical and bent at the waist, while Figure 5.1 illustrates the CG location graphically. It is assumed that the mannequin is symmetrical and the transverse centre of gravity does not have an offset. The centres are for the mannequin fitted with a dry vest and weighing 69.0 kg. Detailed

results of swinging tests for the two conditions specified above are presented in Appendix 2.

Table 5.1 – SWIM Vertical and Longitudinal Centres of Gravity

	Mannequin Configuration	
Centre of Gravity (CG)	Vertical	Bent at waist
Longitudinal (X-axis), mm	134.0	794.8
Transverse (Y-axis), mm	0.0	0.0
Vertical (Z-axis), mm	985.7	301.0

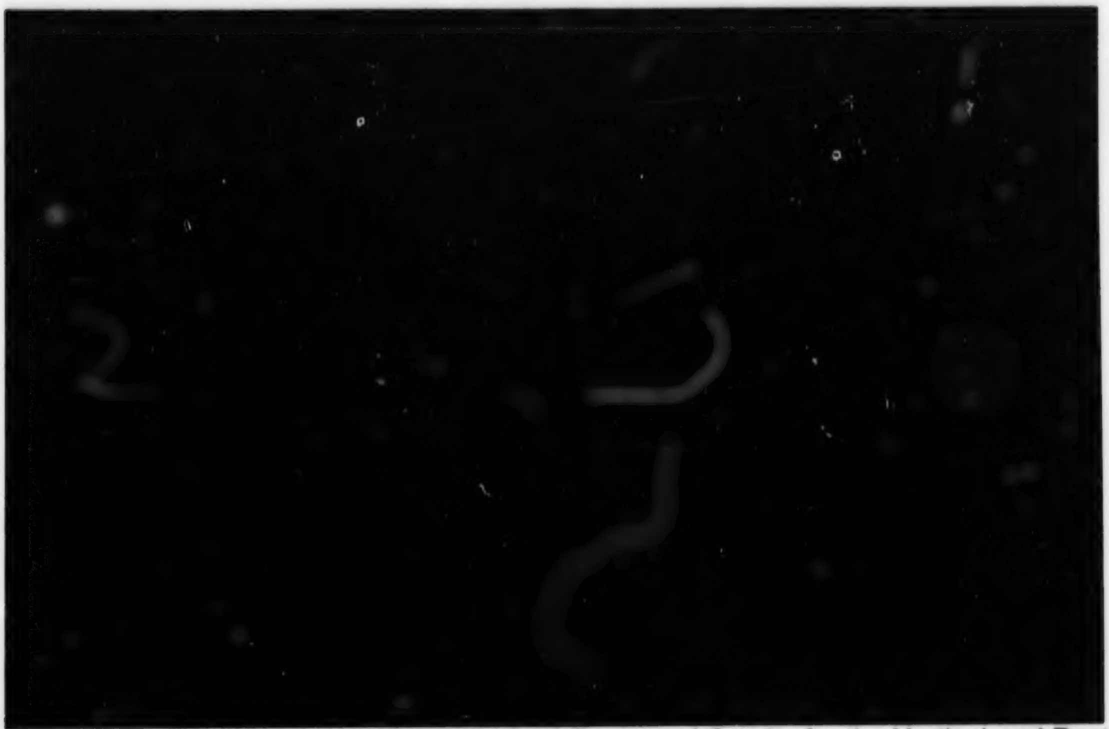


Figure 5.1 – SWIM Vertical and Longitudinal Centres of Gravity for the Vertical and Bent at the Waist Configurations

5.2 Centre of Buoyancy

The experiments for the centre of buoyancy were inconclusive due to either malfunctioning of the sensors or improper set-up.

5.3 Drag Tests

The hydrodynamic drag tests were carried out for the mannequin in four different configurations, namely, horizontal, vertical face-forward, vertical right-shoulder forward and bent at the waist face-forward, for the forward and reverse directions. The supporting frame drag was determined and subtracted from the overall mannequin drag results. The projected areas for the different mannequin configurations were determined from the mannequin manufacturing drawings provided to IMD by the USCG Reference (2). These areas were used to calculate drag coefficients for the mannequin. Tables 5.2 and 5.3 summarize the drag results for the mannequin in the different configurations and for the forward and reverse directions, respectively. A graphical presentation of the drag data is presented in Figure 5.2.

Table 5.2 – Mannequin Forward Drag Results

	Mannequin Forward Drag (N)			
Velocity (m/s)	Horizontal	Bent at Waist	Vertical Face fwd.	Vertical Right Shoulder fwd.
0.10	0.547	1.074	2.261	1.317
0.20	2.517	5.393	9.186	5.543
0.30	4.866	12.087	20.430	12.341
0.40	7.594	21.155	35.992	21.710
0.50	10.699	32.598	55.873	33.651
0.60	14.184	-	-	-
0.70	18.046	-	-	-
0.80	22.287	-	-	-
0.90	26.907	-	-	-
1.00	31.904	-	-	-

Table 5.3 – Mannequin Reverse Drag Results

	Mannequin Reverse Drag (N)			
Velocity (m/s)	Horizontal	Bent at Waist	Vertical Face Rev.	Vertical Right Shoulder Rev.
0.10	0.681	1.320	3.886	2.285
0.20	1.724	4.501	11.389	6.421
0.30	3.812	11.035	25.225	14.153
0.40	6.946	20.923	45.393	25.483
0.50	11.124	34.164	71.894	40.411

The projected areas for the four different configurations were estimated at:
Horizontal: 0.122 m^2
Bent at the Waist: 0.257 m^2
Vertical Face-Forward: 0.537 m^2
Vertical Right Shoulder Forward: 0.308 m^2
Based on the above projected areas and the hydrodynamic drag, the mannequin's drag coefficients for the different configurations can be calculated by the following equation:

$$C_D = \frac{2 \times F}{\rho \times V^2 \times A}$$

Where: C_D Hydrodynamic Drag Coefficient
F Mannequin hydrodynamic drag, N
ρ Water density, kg/m^3
A Projected area, m^2

The mannequin's hydrodynamic drag coefficients for the different configurations and for the forward and reverse directions are summarized in Table 5.4 below.

Table 5.4 – SWIM Average Drag Coefficients

	DRAG COEFFICIENT	
Configuration	Forward	Reverse
Horizontal	0.702	0.795
Bent at Waist	0.995	0.988
Vertical Face Fwd.	0.844	1.060
Vertical Right Shoulder Fwd.	0.881	1.037

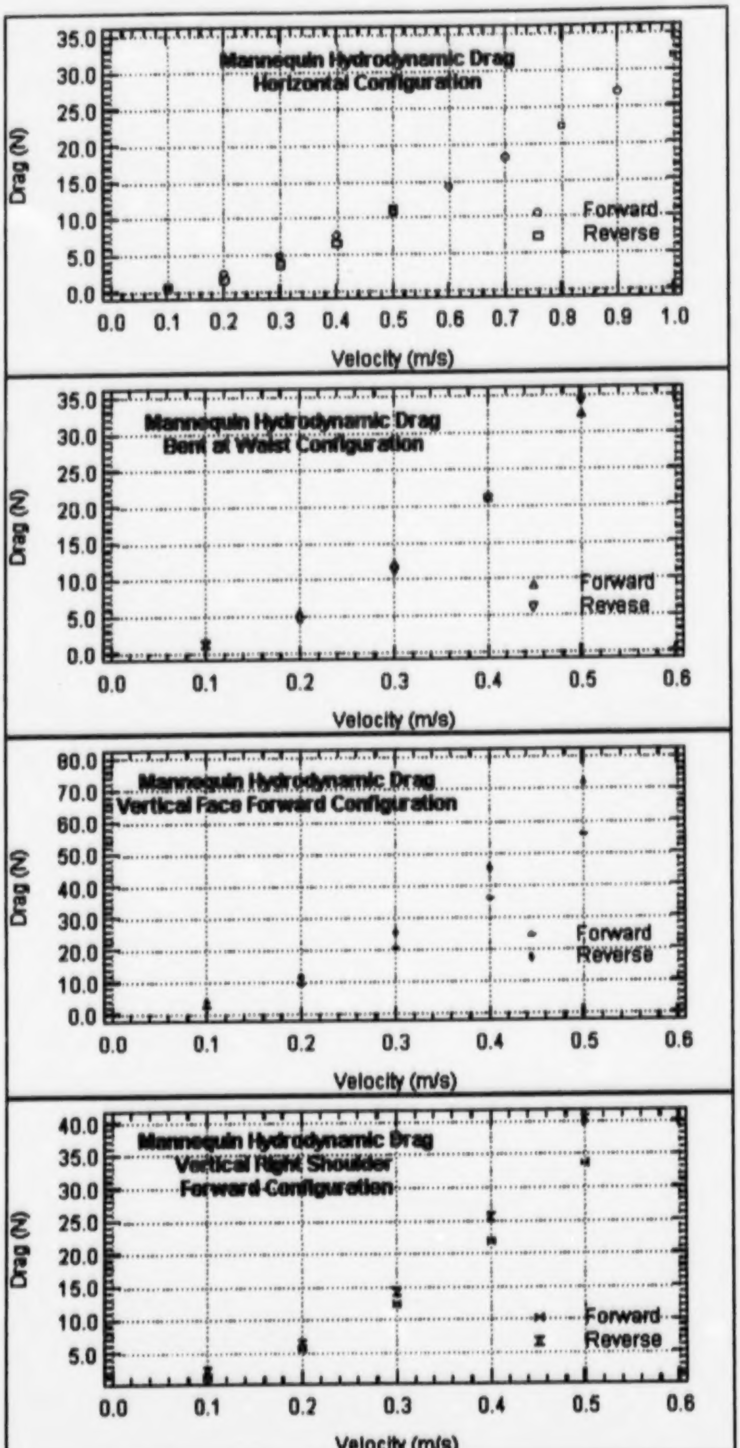


Figure 5.2 - Mannequin Hydrodynamic Drag

5.4 Bottom Release Tests

This series of tests produced unreliable data. The main problem was due to the small rotation of the mannequin in its ascent to the surface. The rotation shadowed some of the markers, which made them invisible to one of the cameras. In order for the system work properly the markers have to be visible to both cameras.

5.5 Regular Wave Tests

The test programme required the generation of three regular waves, which were modelled in terms of wave height and period. The waves were calibrated prior to the test programme without the mannequin in the tow tank. For each calibrated wave, a segment of 20 cycles was chosen to evaluate the wave parameters. The 20-cycle segment was selected by windowing through the entire time trace. The files were defined using the following wave convention:

REG_HαPα_TβPβ_00δ

Where:

REG - indicates regular wave
α - defines the wave height in metres
β - defines the wave period in seconds
δ - defines the incremental number
P - denotes the decimal

For example, the run designated "REG_H0P25_T2P0_002" defines a regular wave with a height of 0.25m and a period of 2.0 seconds, attempt number 2. Zero-crossing analysis was used to determine the average measured wave height and period. The time series data for calibrated waves are given in Appendix 4.

The main statistics of the individual time series corresponding to all measured and calculated channels were analyzed and the following parameters outputted:

- Mean — The mean value of a time series signal y(t).

$$\overline{X} = \frac{1}{N}\sum_{i=1}^{N} Xi$$

- Minimum — The minimum value of a time series signal y(t). The minimum value of Y(I) for I = 1 to N, where N is the number of samples.
- Maximum — The maximum value of a time series signal y(t). The maximum value of Y(I) for I = 1 to N, where N is the number of samples.
- Standard Deviation — The degree to which numerical data tend to spread about an average

$$\sigma = \sqrt{\frac{\sum_{i=1}^{N}\left(x_i - \overline{x}\right)^2}{N}}$$

where: N is the total number of samples

- Variance The square of the standard deviation, σ^2.

A sine curve was fitted through the time series data using the GEDAP program "SINE_FIT". The fitted and acquired data were compared and the amplitude and phase of each motion calculated and converted to ASCII file format.

The mannequin's motions were reduced to response amplitude operators (RAO) obtained from the single amplitude of motion divided by the wave amplitude. The time series data of mannequin motion are given in Appendix 6.

The following figures, Figure 5.3 to 5.5 illustrate the effect on the mannequin motions of changing buoyancy, locking and unlocking the shoulder and hip joints as well as increasing the wave period. A couple of data points also serve to illustrate the repeatability of the data. All the RAO data are summarized in Table 5.5 below.

Table 5.5 Summary Response Amplitude Operators

	Mannequin Set-up			Waves		Response Amplitude Operators					
Test Name	Orientation	Joints	Buoy. (lbs.)	Height (m)	Period (s)	Surge (m/m)	Sway (m/m)	Heave (m/m)	Yaw (deg/m)	Pitch (deg/m)	Roll (deg/m)
WANLS41	Straight	Locked	3	0.25	3.333	0.242	0.013	0.035	6.120	1.290	7.074
WANLS42	Straight	Locked	3	0.25	3.333	0.200	0.051	0.015	6.516	1.435	3.882
WCNLS41	Straight	Locked	3	0.24	2.000	0.304	6.167	0.235	5.783	7.729	0.025
WBLJLS31	Straight	Locked	12	0.24	2.000	0.155	0.181	0.644	12.513	14.602	15.522
WBNLR41	Bent	Locked	3	0.24	2.000	0.327	0.821	0.385	44.876	9.605	0.014
WBNJU3	Bent	Unlocked	3	0.24	2.000	0.223	0.343	0.126	5.230	6.055	0.729
WBNJU1	Bent	Lock/unlock	3	0.24	2.000	3.835	6.865	0.447	5.708	11.020	13.975
WBNJU2	Bent	Lock/unlock	3	0.24	2.000	0.102	0.500	0.566	3.990	16.265	8.223
WBNLS41	Straight	Locked	3	0.23	1.429	0.043	3.293	0.025	15.156	0.154	7.750
WCNLS42	Straight	Locked	3	0.23	1.429	0.331	10.167	0.208	3.450	11.507	2.572

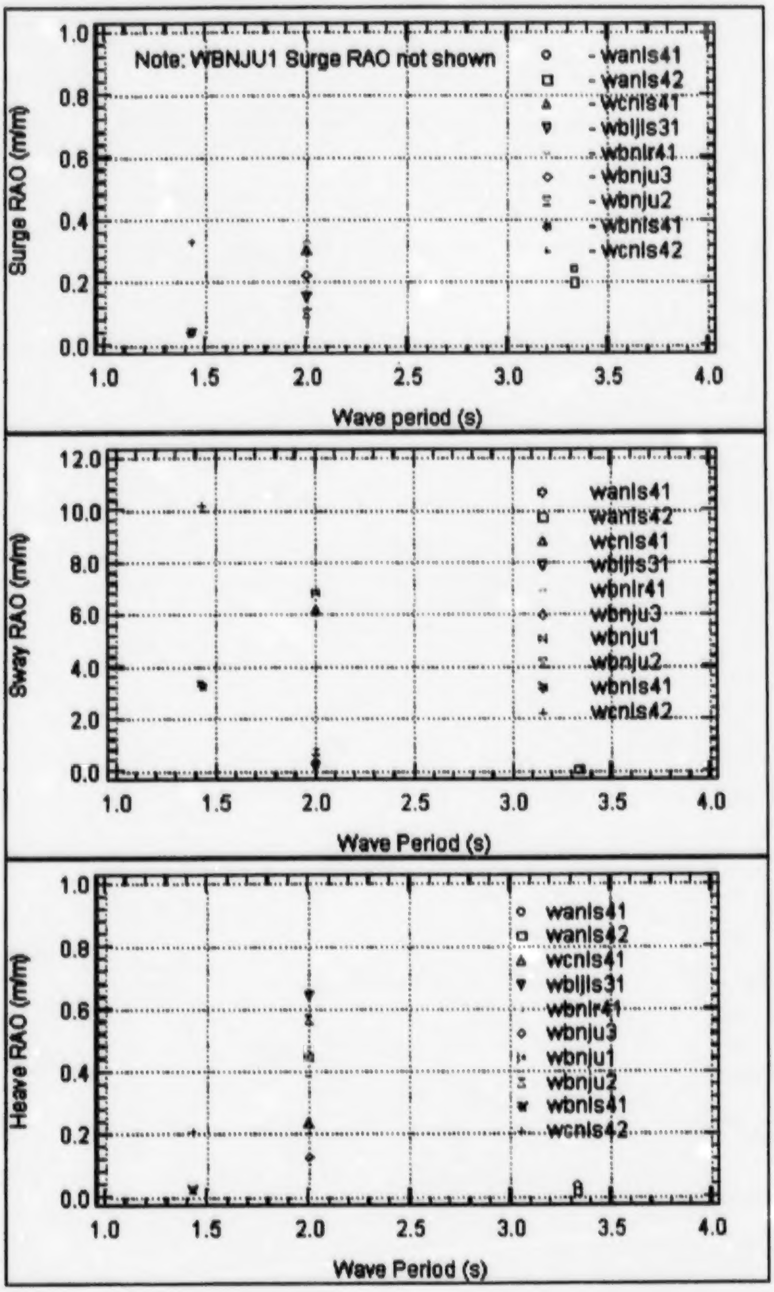


Figure 5.3 - Mannequin Surge, Sway and Heave RAO

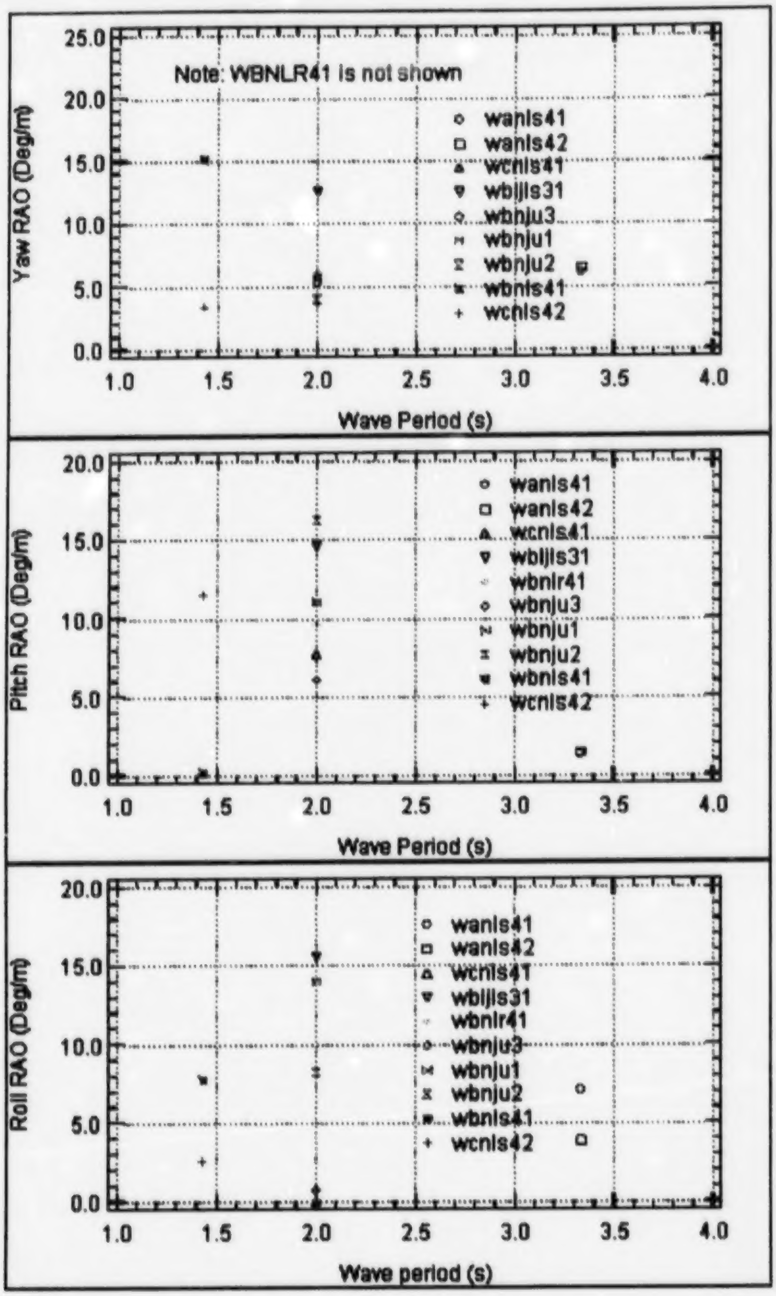


Figure 5.4 - Mannequin Yaw, Pitch and Roll RAO

The following discussion compares the wave test results on the following areas:

- repeatability,

- effects of increasing the mannequin's buoyancy,
- effects of fully unlocking, partially unlocking and fully locking the mannequin's joints,
- effects of wave period.

Tests WANLS41 and WANLS42 were performed to check data repeatability. Close examination of the table and figures show that the response amplitude operators (RAO) have good repeatability except the one for roll.

Buoyancy tests WCNLS41 and WBLJLS31 were aimed at checking the effects of buoyancy increase. Surge and sway RAOs show a slight decrease with increased buoyancy. The opposite holds true for the remaining RAOs, i.e. heave, yaw, pitch, and roll. The increase in buoyancy from three to 12 lb. causes the heave RAO to triple and the yaw and pitch to double. A more pronounced effect is observed on the roll RAO.

Several tests were carried out to identify the effect of locking, WBNLR41, unlocking, WBNJU3 or partially locking, WBNJU1 and WBNJU2, the mannequin's joints. Unlocking the mannequin's joints decreases the linear and rotational RAO values with the exception of the roll RAO that sees an increase and the yaw RAO for which a comparison is not possible due to the extremely high values. Partially locking the joints yields mixed results without a clear increase or decrease of the RAO values. Surge RAO values decrease with the unlocking of the joints. A further decrease is observed with the partial unlocking. Heave, pitch and roll RAO values of the mannequin with joints partially unlocked increase over those in the unlocked and locked conditions. The yaw RAO for unlocked and partially locked mannequin is approximately the same. Partially unlocked heave RAO has values in between those of the fully locked and unlocked.

The effect of increasing the wave period on the mannequin motions was addressed by the following tests: WBNLS41, WCNLS42 (T=1.492s), WCNLS41, (T=2.00s), and WANLS41 and WANLS42 (T= 3.333s). An increase in wave period brings about a decrease in surge, sway and pitch RAOs while the opposite is true for yaw. The heave RAO has a maximum at the 2.0 period while the roll has a minimum at the same period.

5.6 Push-Glide Tests

Push-glide tests were conducted for the mannequin with all joints locked, normal outfit (3 lb. buoyancy) and for three speeds, namely, 0.30, 0.50, and 1.00 m/s. For these tests the Qualisys tree was removed and string loops attached at the mannequin's shoulder and knee holding pins. A purpose-built frame was attached to the towing carriage. The frame was outfitted with four 25 mm tapered pins. They served as attachment points between the mannequin and the frame. At the lower speeds it was hard for the mannequin to slip-off the frame pins. At he higher speed the action was better but it was felt the towing carriage deceleration had to be increased. After the towing carriage was reprogrammed to decelearate at a higher rate several tests were conducted at a speed of 1.00 m/s. In these tests the face-down mannequin slipped off the tapered pins glided approximately 1.00 m and slowly turned face up and returned to its normal floating position. These tests were visual tests and the Institute did not collect data. The mannequin sensors were activated during these tests and the USCG have the results.

6.0 CONCLUSIONS

The series of exploratory experiments on the Sea Water Instrumented Mannequin (SWIM) met with mixed degrees of success. The mannequin's centres of gravity and drag coefficients for a number of configurations were determined successfully. Also successful were the experiments conducted in waves. The same cannot be said for the mannequin's centre of buoyancy experiments and bottom release tests. Both of these tests had several technical problems. Push-glide tests were conducted at the Institute for visual purposes only.

7.0 RECOMMENDATIONS

Data from the Qualisys™, video imaging and the mannequin's own data acquisition system have to be available in real time or shortly after the day experiments are completed in order to determine the limitations of the systems and to evaluate the quality of the sensors data being collected. This latter recommendation will reduce the number of experiments conducted with equipment that produces data that are questionable at best.

The mannequin's sensor data collected with the onboard data acquisition system by the USCG will complement the data collected by the Institute and future data should be presented in a single report.

The determination of the CG and CB of the mannequin for the different testing configurations must be done for the mannequin both in a dry and wet condition.

The neoprene vest used for floatation has to be attached more solidly to the mannequin in order to avoid movement that may contribute to erroneous data.

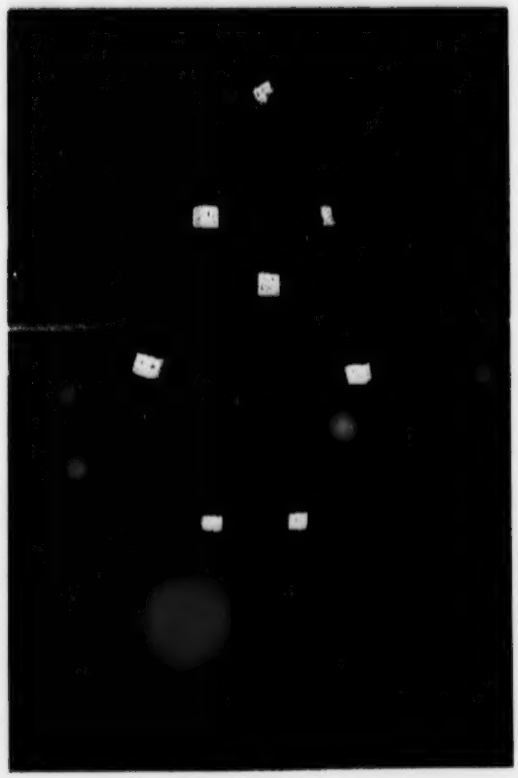
Problems with skin cracks and subsequent water absorption has to be reduced in order to have reliable weight and buoyancy data for the mannequin. Future experiments must not proceed unless all the damaged areas are fixed. It would be advisable to have repair kits available during testing.

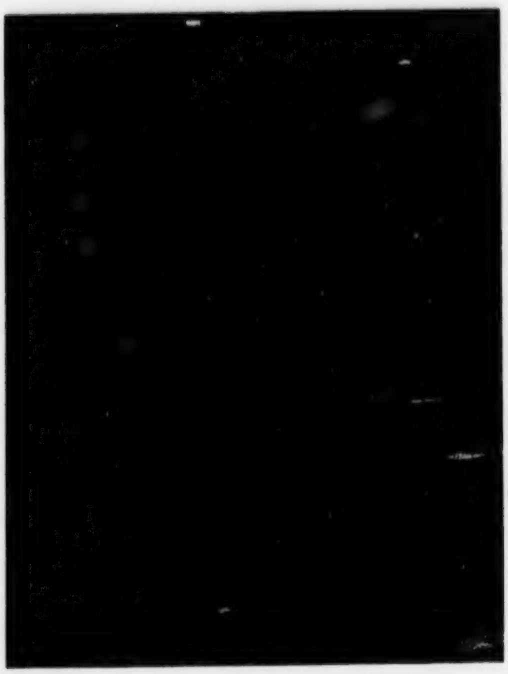
The IMD recommends that some time be given to the IMD personnel to familiarize themselves with the working of the data acquisition systems and sensors calibration and data collection. Also, the availability of the WAFAC and DYNAMAN to the Institute personnel will help in determining the most important parameters to future experiments.

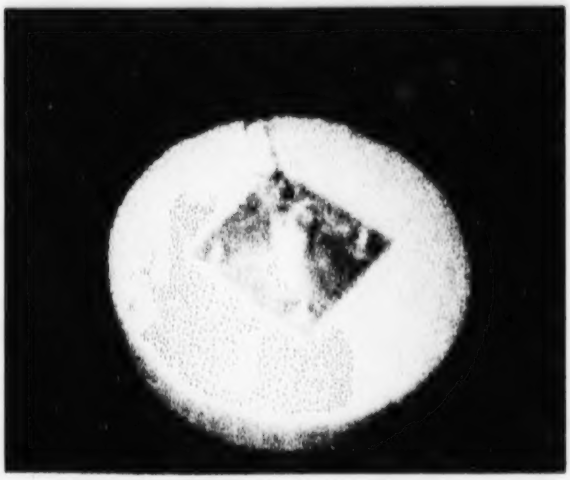
REFERENCES

1. Sullivan, M. (1993) "Design of a Real-Time Motion Tracking System", presented at the 1993 Canadian Conference on Electrical and Computer Engineering, Vancouver, 1993.
2. Sea Water Instrumented Mannequin Manufacturing Drawings (1999).

APPENDIX 1: SELECTED PHOTOGRAPHS OF SWIM







APPENDIX 2: SWIM CENTRES OF GRAVITY AND BUOYANCY

Flat on Back

PROJECT PARTICULARS	
PROJECT DISCRIPTION	SWIM
PROJECT NUMBER	880
MODEL DESCRIPTION	Mannequin
MODEL NUMBER	NA
DATE	3-Aug-99

TARGET VALUES	
LCG (m) wrt AP	NA
VCG (m) wrt Baseline	NA
Radius of Gyration (m)	NA

VALUES TO BE INPUTED

Acceleration due to gravity (g) =	9.807
Measured mass of model (kg) =	69.000

LIST OF TERMINOLOGY

KE = Knife edge
GoBo = Restoring moment of frame without model
GsBs = Restoring moment of frame model, and trimming mass
GcBc = Restoring moment for trimming mass used to level model
GmBm = Restoring moment for the model
Jo = Mass moment of inertia of frame without model
Js = Mass moment of inertia of frame with model, and trimming mass
Jc = Mass moment of inertia of trimming mass used to level model
Jm(ke) = Mass moment of inertia of model about the knife edge
Jm(vcg) = Mass moment of inertia of model about the VCG
K = Radius of Gyration
T = Period

2–2

ESTABLISHING RESTORING MOMENT & MASS MOMENT OF INERTIA FOR FRAME

*GoBo=(Z+L/TAN$)*P*g=* 35.933
*Jo=(T/2pie)^2*GoBo=* 3.101

Applied Load (P) (kg)=	0.824
Transverse distance to applied load from KE* (L) (m)=	0.279
Vertical distance to applied load from KE (Z) (m)=	0.021

Inclining Angles (Degrees)

	Actual Angle (Deg.)	Change in Angle (Deg.)
Initial Angle	0.040	
Apply Load	-3.570	3.610
Remove Load	0.010	3.580
Apply Load	3.640	3.630
Remove Load	0.030	3.610
	Mean Angle=	3.608

Period (T) of Frame

Cycles	Time (sec)	Period (sec)
10	18.530	1.853
10	18.500	1.850
10	18.340	1.834
	Mean=	1.846

2–3

ESTABLISHING RESTORING MOMENT & MASS MOMENT OF INERTIA FOR FRAME AND MODEL

ERECT

*GsBs=(Z+L/TAN$)*P*g=* 258.542

*Js=(T/2pie)^2*GsBs=* 22.535

Applied Load {P} (kg)=	6.454
Transverse distance to applied load from KE* {L} (m)=	0.279
Vertical distance to applied load from KE {Z} (m)=	0.021

Inclining Angles (Degrees)

	Actual Angle (Deg.)	Change in Angle (Deg.)
Initial Angle	0.030	
Apply Load	-3.880	3.910
Remove Load	0.030	3.910
Apply Load	3.990	3.960
Remove Load	0.060	3.930
	Mean Angle=	3.928

Period (T) of Frame

Cycles	Time (sec)	Period (sec)
10	18.560	1.856
10	18.530	1.853
10	18.560	1.856
	Mean=	1.855

CORRECTION FOR TRIMMING MASS

*GcBc=mass*distance*g=* 19.673

*Jc=mass*distance^2=* 0.895

Triming Mass (Kg)=	5
VCG of Trim mass wrt KE (m)=	0.4012
TCG of Trim mass wrt KE (m)=	0.134

ESTABLISHING RESTORING MOMENT & MASS MOMENT OF INERTIA FOR MODEL

GmBm=GsBs-GoBo-GcBc=	202.936
Jm(ke)=Js-Jo-Jc =	18.540

VCG OF MODEL

distance from baseline to KE (m) =	0.434
*CG wrt KE=GmBm/(displacement*g)=*	0.300
VCG of model from baseline =	0.134

MASS MOMENT OF INERTIA OF MODEL ABOUT VCG OF MODEL

*Jm(vcg)=Jm(ke)-displacement*dist.^2=*	12.334

RADIUS OF GYRATION OF MODEL

K=(Jm(vcg)/displacement)^0.5 =	0.423

SUMMARY

	TARGET	ACTUAL	PERCENT ERROR
LCG (m) wrt Reference Line	NA	0.0097 (toward head)	#VALUE!
VCG (m) wrt base (Lying on Back)	NA	0.134	#VALUE!
Radius of Gyration (m)	NA	0.423	#VALUE!

SITTING POSITION

PROJECT PARTICULARS

PROJECT DISCRIPTION	SWIM
PROJECT NUMBER	880
MODEL DESCRIPTION	Mannequin
MODEL NUMBER	NA
DATE	3-Aug-99

TARGET VALUES

LCG (m) wrt AP	NA
VCG (m) wrt Baseline	NA
Radius of Gyration (m)	NA

VALUES TO BE INPUTED

Acceleration due to gravity (g) =	9.807
Measured mass of model (kg) =	69.000

LIST OF TERMINOLOGY

KE = Knife edge
GoBo = Restoring moment of frame without model
GsBs = Restoring moment of frame model, and trimming mass
GcBc = Restoring moment for trimming mass used to level model
GmBm = Restoring moment for the model
Jo = Mass moment of inertia of frame without model
Js = Mass moment of inertia of frame with model, and trimming mass
Jc = Mass moment of inertia of trimming mass used to level model
Jm(ke) = Mass moment of inertia of model about the knife edge
Jm(vcg) = Mass moment of inertia of model about the VCG
K = Radius of Gyration
T = Period

ESTABLISHING RESTORING MOMENT & MASS MOMENT OF INERTIA FOR FRAME

*GoBo=(Z+L/TAN$)*P*g=*	35.933
*Jo=(T/2pie)^2*GoBo=*	3.101

Applied Load (P) (kg)=	0.824
Transverse distance to applied load from KE* (L) (m)=	0.279
Vertical distance to applied load from KE (Z) (m)=	0.021

Inclining Angles (Degrees)

	Actual Angle (Deg.)	Change in Angle (Deg.)
Initial Angle	0.040	
Apply Load	-3.570	3.610
Remove Load	0.010	3.580
Apply Load	3.640	3.630
Remove Load	0.030	3.610
	Mean Angle=	3.608

Period (T) of Frame

Cycles	Time (sec)	Period (sec)
10	18.530	1.853
10	18.500	1.850
10	18.340	1.834
	Mean=	1.846

ESTABLISHING RESTORING MOMENT & MASS MOMENT OF INERTIA FOR FRAME AND MODEL

SITTING

*GsBs=(Z+L/TAN$)*P*g=*	145.633
*Js=(T/2pie)^2*GsBs=*	15.182

Applied Load {P} (kg)=	4.000
Transverse distance to applied load from KE* {L} (m)=	0.279
Vertical distance to applied load from KE {Z} (m)=	0.021

Inclining Angles (Degrees)

	Actual Angle (Deg.)	Change in Angle (Deg.)
Initial Angle	0.090	
Apply Load	-4.270	4.360
Remove Load	0.080	4.350
Apply Load	4.400	4.320
Remove Load	0.140	4.260
	Mean Angle=	4.323

Period (T) of Frame

Cycles	Time (sec)	Period (sec)
10	20.430	2.043
10	20.180	2.018
10	20.250	2.025
	Mean=	2.029

CORRECTION FOR TRIMMING MASS

*GcBc=mass*distance*g=*	19.673
*Jc=mass*distance^2=*	2.390

Triming Mass (Kg)=	5
VCG of Trim mass wrt KE (m)=	0.4012
TCG of Trim mass wrt KE (m)=	0.563

ESTABLISHING RESTORING MOMENT & MASS MOMENT OF INERTIA FOR MODEL

GmBm=GsBs-GoBo-GcBc=	90.026
Jm(ke)=Js-Jo-Jc =	9.691

VCG OF MODEL

distance from baseline to KE (m) =	0.434
*CG wrt KE=GmBm/(displacement*g)=*	0.133
VCG of model from baseline =	0.301

MASS MOMENT OF INERTIA OF MODEL ABOUT VCG OF MODEL

*Jm(vcg)=Jm(ke)-displacement*dist.^2=*	8.470

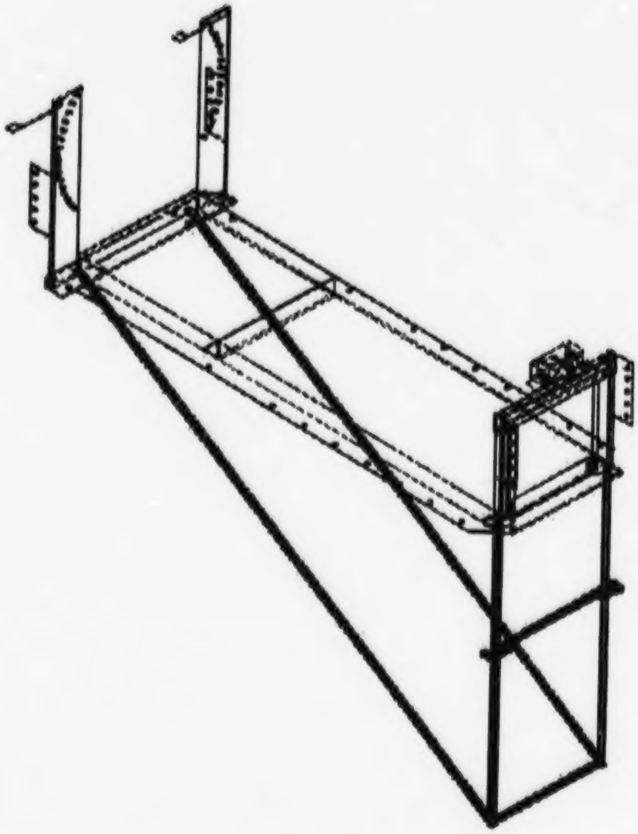
RADIUS OF GYRATION OF MODEL

K=(Jm(vcg)/displacement)^0.5 =	0.350

SUMMARY

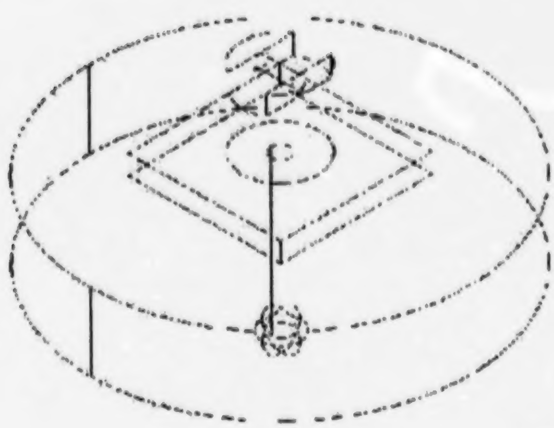
	TARGET	ACTUAL	PERCENT ERROR
LCG (m) wrt Reference Line	NA	0.0291 (away from feet)	#VALUE!
VCG (m) wrt base	NA	0.301	#VALUE!
Radius of Gyration (m)	NA	0.350	#VALUE!

APPENDIX 3: TESTS APPARATUS, DESIGN AND CONSTRUCTION



Drag Frame

Push-Glide Frame



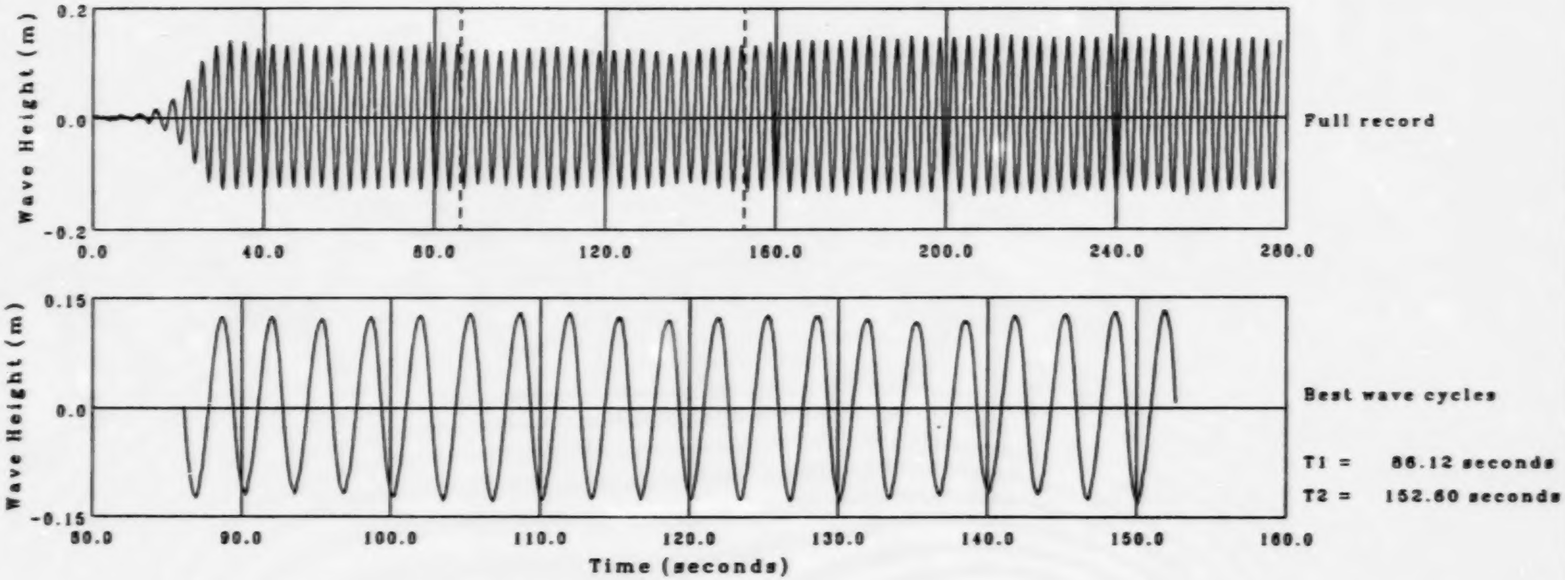
Bottom Release Apparatus

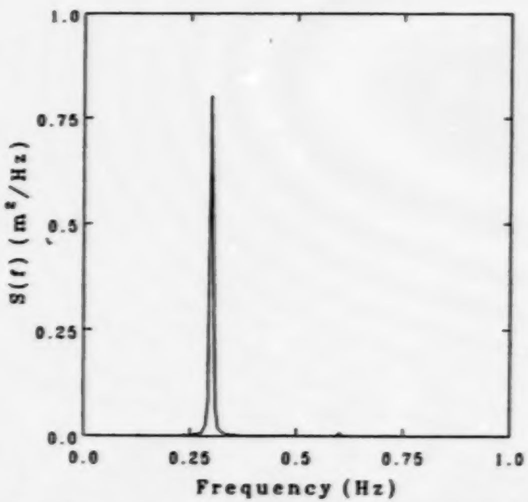
APPENDIX 4: REGULAR WAVES

SWIM Preliminary Experiments
Regular Wave Tests

NRC-IMD

Analyzed: 02-SEP-1999 10:19:36
Acquired: 23-FEB-1999 10:12:42





Full record wave parameters:		
Average wave height	= 0.26 m	
Average wave period	= 3.33 seconds	
		Target /
Best wave cycles parameters:		**(Tolerance):**
Average wave height	= 0.25 m	0.25 m
Average wave period	= 3.32 seconds	3.33 seconds
Deviation from target height	= 0.67 %	(5.0 %)
Wave height stability	= 9.41 %	(5.0 %)
Wave crest stability	= 4.35 %	(2.5 %)

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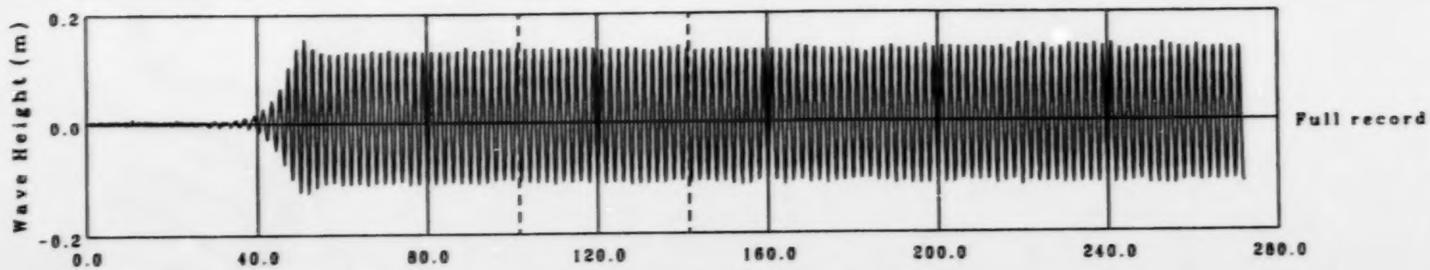
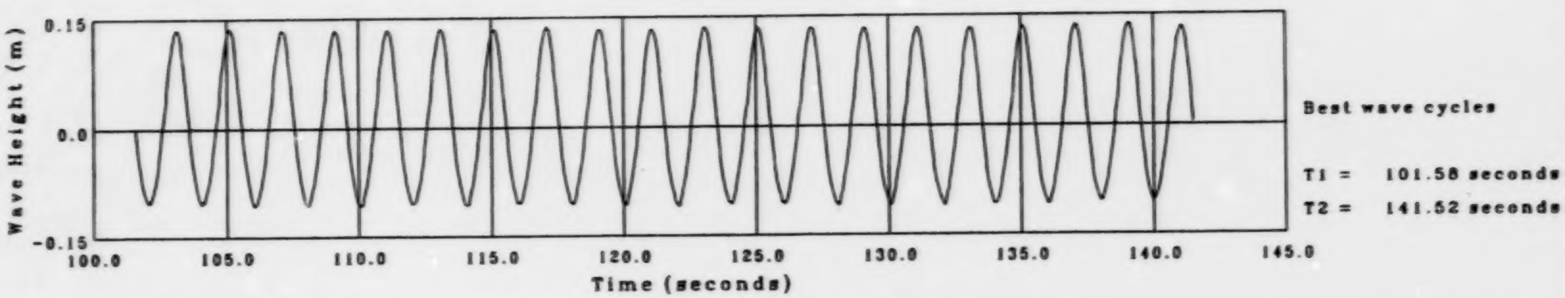
Figure A2 HOP25_T3P33_CAL_001

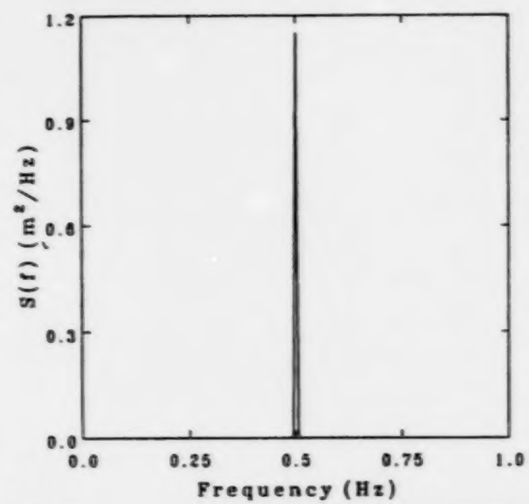
SWIM Preliminary Experiments
Regular Wave Tests

NRC-IMD

Analyzed: 02-SEP-1999 10:17:08
Acquired: 23-FEB-1999 11:26:03







Full record wave parameters:		
Average wave height	= 0.24 m	
Average wave period	= 2.00 seconds	
		Target /
Best wave cycles parameters:		**(Tolerance):**
Average wave height	= 0.24 m	0.25 m
Average wave period	= 2.00 seconds	2.00 seconds
Deviation from target height	= 2.98 %	(5.0 %)
Wave height stability	= 2.79 %	(5.0 %)
Wave crest stability	= 2.05 %	(2.5 %)

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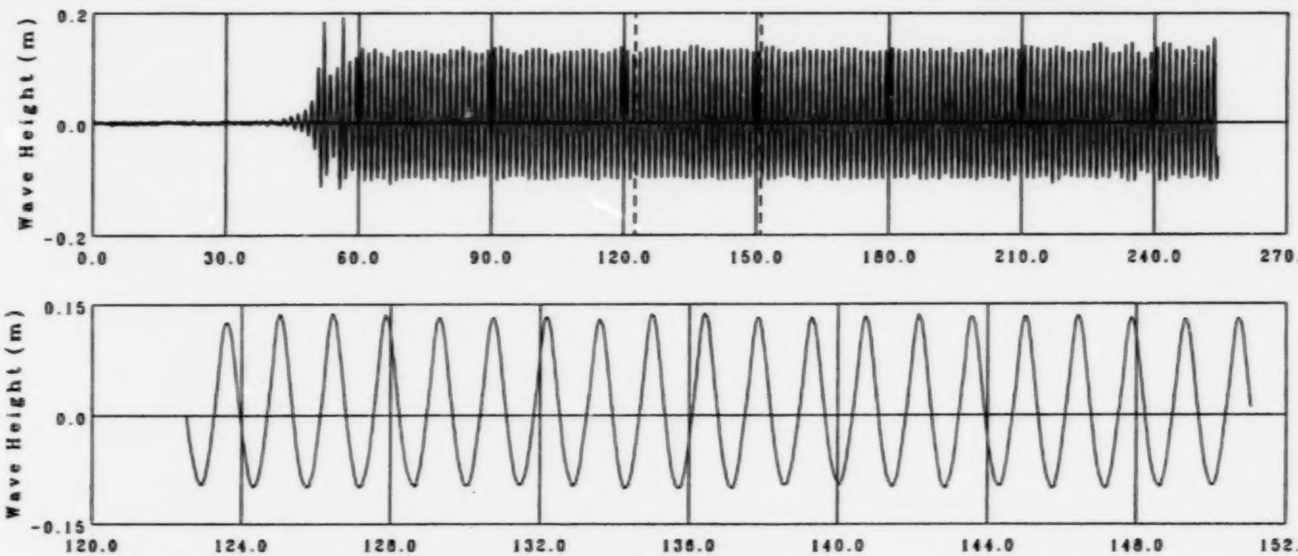
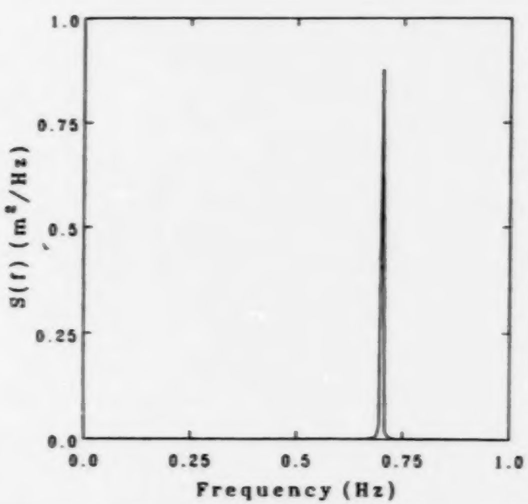
Figure A2 HOP25_T2P0_CAL_002

SWIM Preliminary Experiments
Regular Wave Tests

NRC-IMD

Analyzed: 02-SEP-1999 10:17:50
Acquired: 23-FEB-1999 10:40:00





Full record wave parameters:		
Average wave height	= 0.23 m	
Average wave period	= 1.43 seconds	
		Target / (Tolerance):
Best wave cycles parameters:		
Average wave height	= 0.23 m	0.25 m
Average wave period	= 1.43 seconds	1.43 seconds
Deviation from target height	= 6.99 %	(5.0 %)
Wave height stability	= 4.68 %	(5.0 %)
Wave crest stability	= 2.87 %	(2.5 %)

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Figure A2 HOP25_T1P429_CAL_003

APPENDIX 5: VIDEO LOG

S.W.I.M. Tests (February 18, 1999 to March 6, 1999)

Run File Names & Status / S.W.I.M. Test 1999							
CCG File Name	Tow Tank File Names	Qualysis File Name	Video Log	Test Condition	Test Data Status	Qualysis Status	Comments
-	-	BR4MQ227.QUA	Tape 1 / 09:30	Bottom Release	-	??	Correct accelerometer
BR4MQ227	BR4MQ27A.QUA	BR4MQ27A.QUA	00:09:36	@4.0m, No	OK	??	sensitivity values:
	BR4MQ27B.QUA	BR4MQ27B.QUA	00:10:23	Pre-trigger.	False Start	OK	Ch#3 = X = 1.394mv/g/v
	BR4MQ27C.QUA	BR4MQ27C.QUA	00:11:31		OK	??	Ch#2 = Z = 1.480mv/g/v
	BR4MQ27D.QUA	BR4MQ27D.QUA	00:12:03		OK	??	Ch#1 = Y = 1.4979mv/g/v
	BR4MQ27E.QUA	BR4MQ27E.QUA	00:12:28		OK	No Good	
	BR4MQ27F.QUA	BR4MQ27F.QUA	00:13:22		OK	??	
	BR4MQ27G.QUA	BR4MQ27G.QUA	-		String Tangled	No File Saved	
	BR4MQ27H.QUA	BR4MQ27H.QUA	00:13:44		OK	??	
BR7M225A	-	-	00:14:19	B.R. 7.0M	OK	NONE	Arms Not Tight / Depth = 6.49m
BR7M225A	-	-	-	B.R. 7.0M	OK	NONE	Arms Tight / Joints Straight
BR5M225A	-	-	00:17:31	B.R. 5.0M	OK	NONE	Joints Locked Straight / 12.5 sec
BR5M225A	-	-	00:17:33	B.R. 5.0M	OK	NONE	13.5 sec rise
BR5M225A	-	-	00:17:37	B.R. 5.0M	OK	NONE	13.9 sc rise
BR4M226A	-	-	00:10:41	B.R. 4.0M	No Good	NONE	Pressure transducer reset to 1PSI
BR4M226B	-	-	00:11:03	B.R. 4.0M	OK	NONE	
BR4M226B	-	-	00:11:07	B.R. 4.0M	No Good	NONE	
BR4M226B	-	-	00:11:20	B.R. 4.0M	OK	NONE	
BR4M226B	-	-	00:12:02	B.R. 4.0M	OK	NONE	
CBJLS227	-	-	?	Center of	No Good	NONE	Neck was Loose
CBJLS227	-	-	?	Bouyancy	OK	NONE	From Ankles
CBJLS227	-	-	?	Measurements	OK	NONE	From Knees
CBJLS227	-	-	?		OK	NONE	From Middle of Shoulders
CBJLS227	-	-	?		OK	NONE	From Head Bolt
CBJLS228	-	-	?	Center of	OK (Feet)	NONE	These Files may or
CBJLS228	-	-	?	Bouyancy	OK (Chest)	NONE	may not exist.
CBJLS228	-	-	?	Measurements	OK (Head)	NONE	
CBJLS228	-	-	?		OK (Knee)	NONE	
CBJLS28B	-	-	?	Center of	OK	NONE	Attached at Ankles fromFront
CBJLS28B	-	-	?	Bouyancy	OK	NONE	Attached at Knees at Back
CBJLS28B	-	-	?	Measurements	OK	NONE	Attached at Torso Upper Chest
CBJLS28B	-	-	?		OK	NONE	Attached at head Eyebolt

5-2

S.W.I.M. Tests (February 18, 1999 to March 6, 1999)

CCG File Name	Tow Tank File Names	Qualysis File Name	Video Log	Test Condition	Test Data Status	Qualysis Status	Comments
BR4M31LS	BR4M31LA.QUA	BR4M31LA.QUA	00:14:39	B.R. 4.0M	OK	No Good	Release at Ankles
BR4M31LS	BR4M31LB.QUA	BR4M31LB.QUA	00:15:15	B.R. 4.0M	OK	No Good	7.65s to surface
BR4M31LS	BR4M31LC.QUA	BR4M31LC.QUA	00:16:21	B.R. 4.0M	OK	No Good	7.59s to surface
BR4M31LS	BR4M31LD.QUA	BR4M31LD.QUA	00:17:00	B.R. 4.0M	OK	No Good	7.7s to surface
NOIW3S10	-	-	-	P=3s, H=10in	OK	NONE	Sampling before waves hit Manikin
NOIW3S10	-	-	-	P=3s, H=10in	OK	NONE	Sampling after waves hit Manikin
BR3M31NS	BR3M31NA	BR3M31NA	00:18:30	B.R. 3.0M	OK	No Good	Normal Outfit (3lbs)
BR3M31NS	BR3M31NB	BR3M31NB	00:19:15	B.R. 3.0M	OK	No Good	Normal Outfit (3lbs)
BR3M31NS	BR3M31NC	BR3M31NC	00:19:55	B.R. 3.0M	OK	OK	Normal Outfit (3lbs)
BR3MNH32	BR3MNH2A	BR3MNH2A	00:22:04	B.R. 3.0M	No Good	OK	Normal Outfit (4lbs Bouyant)
BR3MNH32	BR3MNH2B	BR3MNH2B	00:23:05	B.R. 3.0M	OK	OK	Left to Angle down
BR3MNH32	BR3MNH2C	BR3MNH2C	00:23:44	B.R. 3.0M	OK	OK	Hold feet for Level Release
BR3MNH32	BR3MNH2D	BR3MNH2D	00:24:22	B.R. 3.0M	OK	OK	Hold feet for Level Release
BR3MNH32	BR3MNH2E	BR3MNH2E	00:24:59	B.R. 3.0M	OK	OK	Hold feet for Level Release
BR3MLH2A	BR3MLH2A	BR3MLH2A	00:25:31	B.R. 3.0M	OK	No Good	Horiz. Lightweight (12lbs)
BR3MLH2A	BR3MLH2B	BR3MLH2B	00:25:59	B.R. 3.0M	OK	No Good	Horiz. Lightweight (12lbs)
BR3MLH2A	BR3MLH2C	BR3MLH2C	00:26:38	B.R. 3.0M	OK	No Good	Horiz. Lightweight (12lbs)
BR3MLH2A	BR3MLV2A	BR3MLV2A	00:27:23	B.R. 3.0M	OK	OK	Vert. Lightweight (12lbs)
BR3MLH2A	BR3MLV2B	BR3MLV2B	00:28:04	B.R. 3.0M	OK	OK	Vert. Lightweight (12lbs)
BR3MLH2A	-	-	-	B.R. 3.0M	No Good	No Run File	Vert. Lightweight (12lbs)
BR3MLH2A	BR3MLV2C	BR3MLV2C	00:29:42	B.R. 3.0M	OK	OK	Vert. Lightweight (12lbs)
BR3MLR32	BR3MLR2A	BR3MLR2A	00:30:03	B.R. 3.0M	OK	No Good	Bent at Waist Lightweight (12lbs)
BR3MLR32	BR3MLR2B	BR3MLR2B	00:30:28	B.R. 3.0M	OK	?	Bent at Waist Lightweight (12lbs)
BR3MLR32	BR3MLR2C	BR3MLR2C	00:30:55	B.R. 3.0M	No Good	?	Bent at Waist Lightweight (12lbs)
BR3MNR32	BR3MNR2A	BR3MNR2A	00:32:37	B.R. 3.0M	OK	No Good	Bent at Waist Normal Weight (4lbs)
BR3MNR32	BR3MNR2B	BR3MNR2B	00:33:08	B.R. 3.0M	OK	No Good	Bent at Waist Normal Weight (4lbs)
BR3MNR32	BR3MNR2C	BR3MNR2C	00:33:58	B.R. 3.0M	OK	No Good	Bent at Waist Normal Weight (4lbs)
BR3MNR32	-	-	-	B.R. 3.0M	OK		Bent at Waist Normal Weight (4lbs)
BR3MNR32	BR3MNR2D	BR3MNR2D	00:34:35	B.R. 3.0M	No Good	OK	Bent at Waist Normal Weight (4lbs)
BR3MNR32	BR3MNR2E	BR3MNR2E	00:35:12/ 36:19	B.R. 3.0M	OK	OK	Bent at Waist Normal Weight (4lbs)
BR3MNR32	BR3MNR2F	BR3MNR2F	00:36:55	B.R. 3.0M	OK	OK	Bent at Waist Normal Weight (4lbs)
BR3MNR32	BR3MNR2G	BR3MNR2G	00:37:25	B.R. 3.0M	OK	OK	Bent at Waist Normal Weight (4lbs)

S.W.I.M. Tests (February 18, 1999 to March 6, 1999)

CCG File Name	Tow Tank File Names	Qualysis File Name	Video Log	Test Condition	Test Data Status	Qualysis Status	Comments
WBLJLS3				f=0.5Hz L=6.25	OK		Before waves hit SWIM (12lbs)
WBLJLS3				f=0.5Hz L=6.25	OK		After waves hit SWIM (12lbs)
WBLJLS3				f=0.5Hz L=6.25	OK		After waves hit SWIM (12lbs)
WANLS4				Calm water	OK		Calm water (Dead in Water)(3lbs)
WANLS4			00:21:59??	f=0.3hz L=14	OK		Before waves hit SWIM (3lbs)
WANLS4			00:24:36??	f=0.3hz L=14	OK		After Waves hit SWIM (3lbs)
WANLS4				f=0.3hz L=14	OK		After Waves hit SWIM (3lbs)
WANLS4				f=0.3hz L=14	OK		Calm water?? (Dead in Water) (3lbs)
WANLS4				f=0.3hz L=14	OK		Before waves hit SWIM (3lbs)
WANLS4				f=0.5hz L=3.2	OK		Before waves hit SWIM (3lbs)
WANLS4				f=0.5hz L=3.2	OK		Before waves hit SWIM (3lbs)
WANLS4				f=0.5hz L=3.2	OK		Before waves hit SWIM (3lbs)
WANLS4				f=0.7hz L=6.25	OK		Before waves hit SWIM (3lbs)
WANLS4				f=0.7hz L=6.25	OK		Before waves hit SWIM (3lbs)
WANLS4				f=0.7hz L=6.25	OK		Before waves hit SWIM (3lbs)
WBNLR4			00:08:52	f=0.5hz L=6.25	OK		Before Waves hit SWIM (3lbs)
WBNLR4				f=0.5hz L=6.25	OK		Before Waves hit SWIM (3lbs)
WBNJU			00:13:36	f=0.5hz L=6.25	OK		Before Waves hit SWIM (3lbs)
WBNJU			00:17:41	f=0.5hz L=6.25	OK		B.W.H SWIM/Wave Height=0.3 (3lbs)
WBNJU				f=0.5hz L=6.25	OK		B.W.H SWIM/Wave Height=0.3 (3lbs)
WBNJU				f=0.5hz L=6.25	OK		Face down, legs locked. BWH(3lbs)
WBNLS4				f=0.5 L=3.0	OK		
WCNLS4				f=0.7 L=6.25	OK		
WCNLS4				f=0.7 L=6.25	OK		
PGNJLS				V=0.3m/s	No Good		Carriage too Slow
PGNJLS				V=0.5m/s	No Good		Carriage too Slow
PGNJLS				V=1.0m/s	OK		Carriage Speed used for all tests
PGNJLS				V=1.0m/s	OK		Carriage Speed used for all tests
PGNJLS				V=1.0m/s	OK		Carriage Speed used for all tests
PGNJLS				V=1.0m/s	OK		Carriage Speed used for all tests

APPENDIX 6: DISPLACEMENT PLOTS

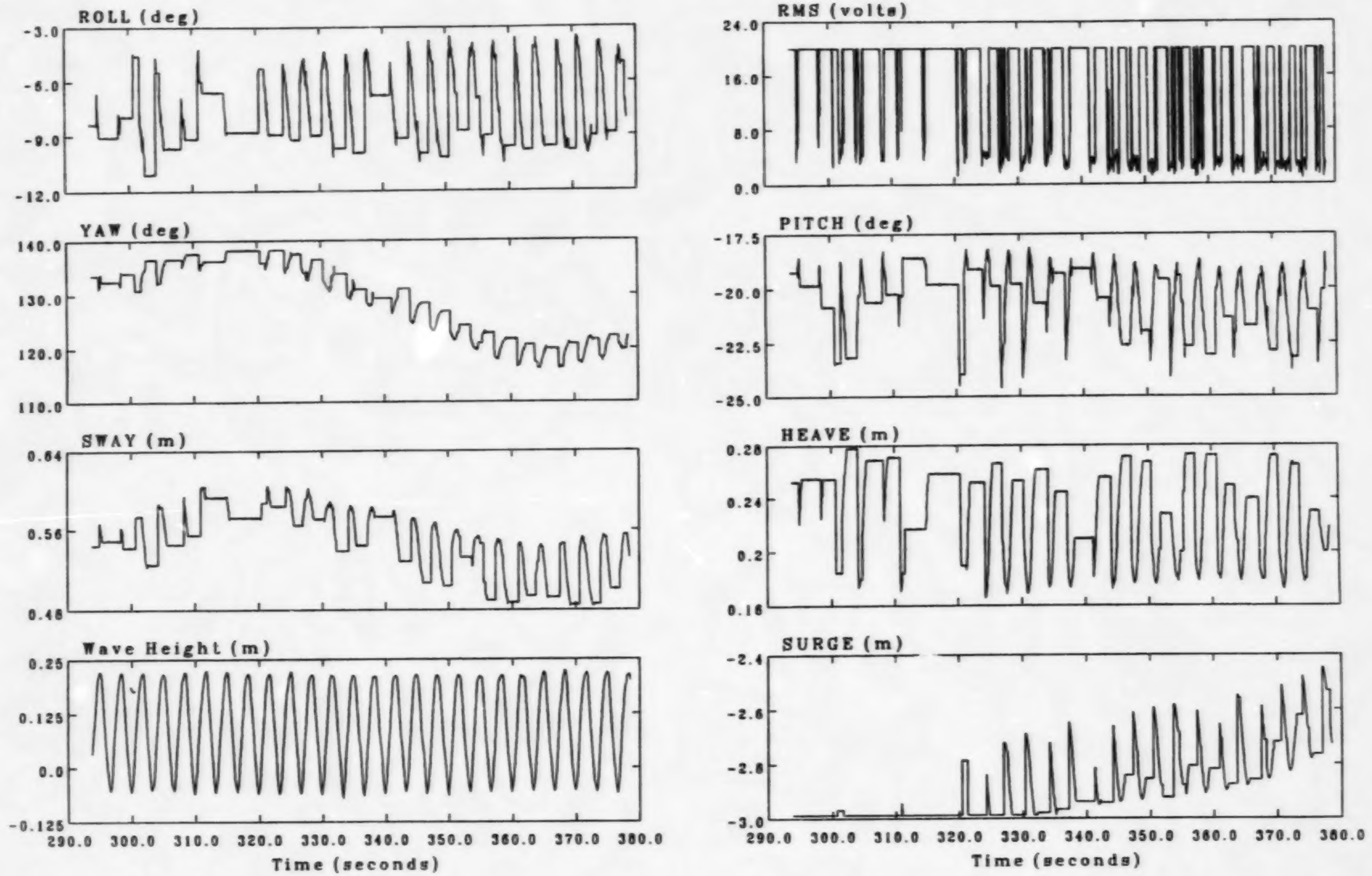
```
Analysis Date/Time =  8-SEP-1999 17:07:41
Acquired Date/Time = 04-MAR-1999 09:28:41
Input File         =  CH_S1
Output File        =  WANLS4_001
Number of Samples  =  4239
Segment Start Time =  293.78 seconds
Segment End Time   =  378.54 seconds
```

Description	Unit	Min	Max	Mean	S.D.	Chan
Carriage Speed	m/s	-0.0079393	0.0034914	-0.0021849	0.0014732	1
Wave Height	m	-0.067649	0.22413	0.092745	0.094394	2
SURGE	m	-2.9878	-2.4477	-2.8866	0.12505	3
SWAY	m	0.48308	0.60392	0.54621	0.031934	4
HEAVE	m	0.16597	0.27833	0.23334	0.032336	5
YAW	deg	116.10	138.27	129.24	6.9689	6
PITCH	deg	-24.620	-18.110	-20.473	1.4158	7
ROLL	deg	-11.143	-3.4877	-7.9560	1.8716	8
RMS	volts	0.71588	20.063	14.388	7.7400	9

SWIM Preliminary Experiments
Regular Wave Tests

NRC - IMD

Analyzed: 8-SEP-1999 17:07:41
Acquired: 04-MAR-1999 09:28:41



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GENERATED BY: DPELLEY | CHECKED BY: | APPROVED BY:

Figure 1 WANLS4_001

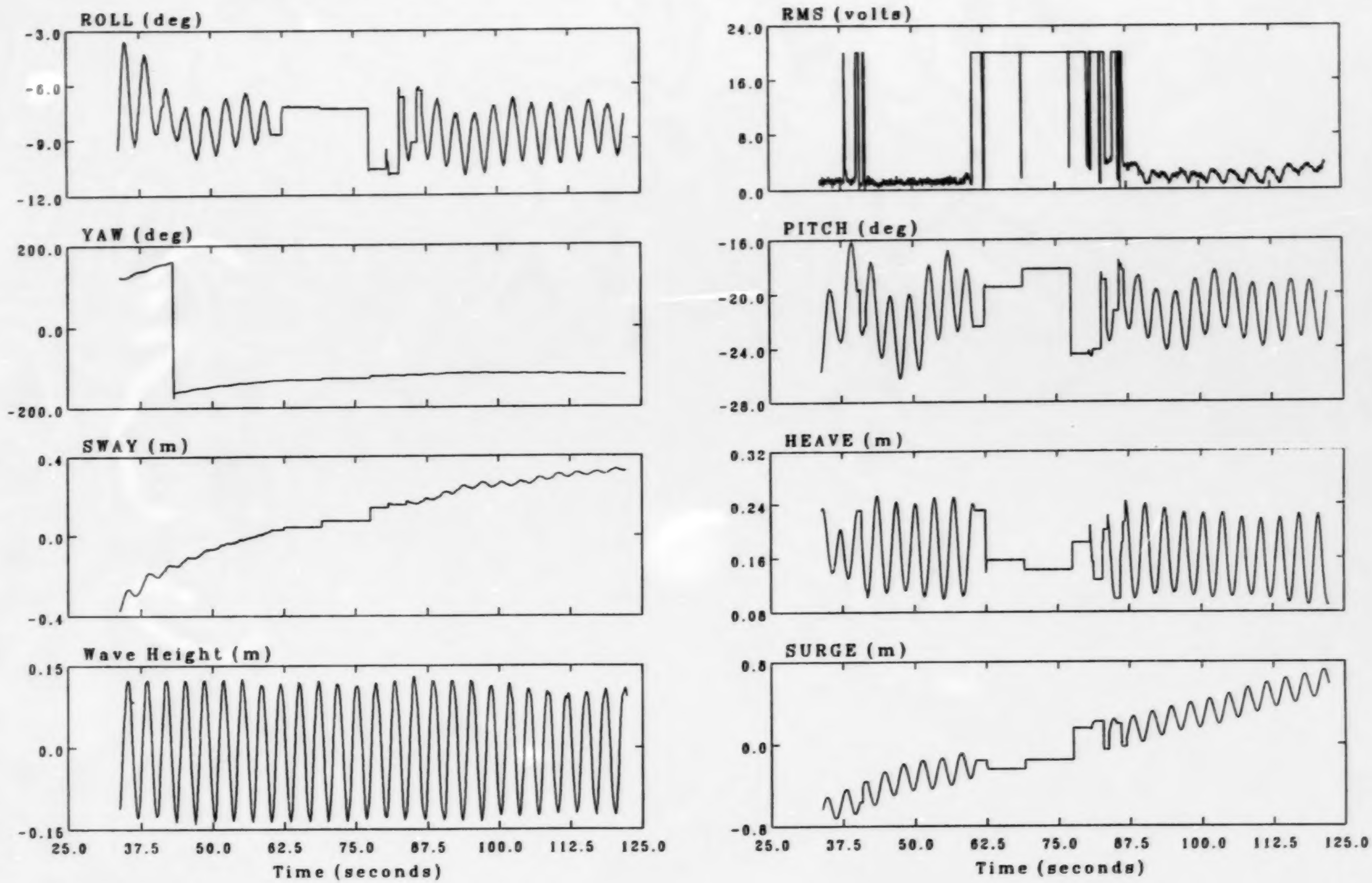
Analysis Date/Time = 8-SEP-1999 17:09:45
Acquired Date/Time = 04-MAR-1999 09:42:44
Input File = CH_S1
Output File = WANLS4_002
Number of Samples = 4423
Segment Start Time = 33.860 seconds
Segment End Time = 122.30 seconds

Description	Unit	Min	Max	Mean	S.D.	Chan
Carriage Speed	m/s	-0.0063064	0.0018584	-0.0018838	0.0014360	1
Wave Height	m	-0.13794	0.12761	0.00047524	0.088147	2
SURGE	m	-0.72353	0.72211	0.0077515	0.35995	3
SWAY	m	-0.37566	0.33253	0.097261	0.17209	4
HEAVE	m	0.089352	0.25285	0.16392	0.042844	5
YAW	deg	-175.42	161.88	-97.490	83.272	6
PITCH	deg	-26.245	-16.155	-20.961	2.1718	7
ROLL	deg	-10.967	-3.5757	-8.2182	1.3671	8
RMS	volts	0.044447	20.063	6.8596	8.1314	9

SWIM Preliminary Experiments
Regular Wave Tests

NRC - IMD

Analyzed: 8-SEP-1999 17:09:45
Acquired: 04-MAR-1999 09:42:44



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GENERATED BY: DPELLEY	CHECKED BY:	APPROVED BY:

Figure 1 WANLS4_002

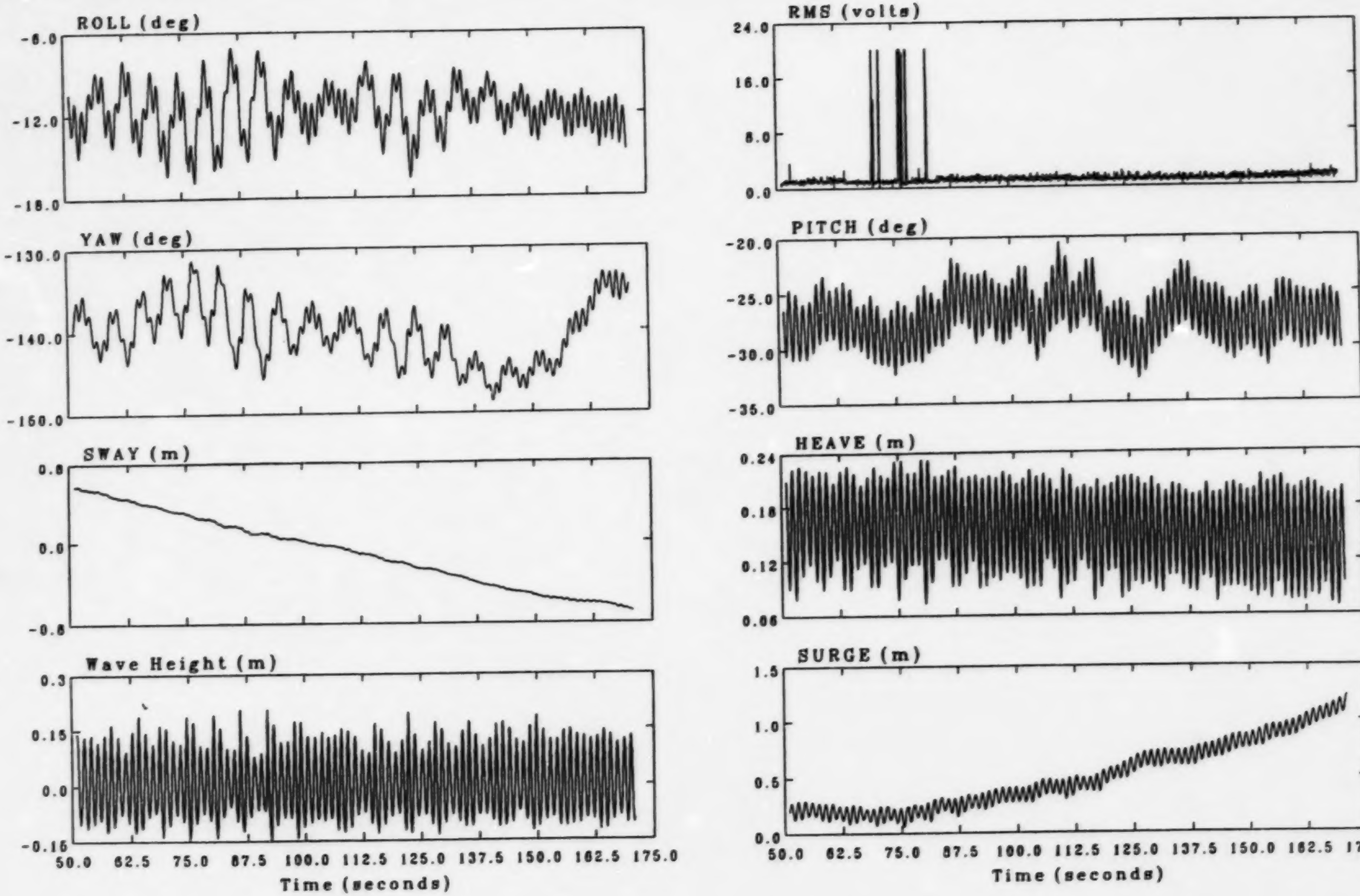
```
Analysis Date/Time =  8-SEP-1999 17:11:51
Acquired Date/Time = 04-MAR-1999 10:11:00
Input File         =  CH_S1
Output File        =  WCNLS4_001
Number of Samples  =  5996
Segment Start Time =  51.020 seconds
Segment End Time   =  170.92 seconds
```

Description	Unit	Min	Max	Mean	S.D.	Chan
Carriage Speed	m/s	-0.017737	0.068810	0.036153	0.010697	1
Wave Height	m	-0.14828	0.20591	0.0039461	0.083618	2
SURGE	m	0.055722	1.2207	0.49775	0.29415	3
SWAY	m	-0.69234	0.56578	-0.099186	0.36706	4
HEAVE	m	0.068457	0.23177	0.15292	0.041796	5
YAW	deg	-148.59	-131.26	-140.21	3.7384	6
PITCH	deg	-32.855	-20.591	-27.185	2.2738	7
ROLL	deg	-16.873	-7.0733	-11.753	1.7628	8
RMS	volts	0.044447	20.063	1.2624	1.6905	9

SWIM Preliminary Experiments
Regular Wave Tests

NRC - IMD

Analyzed: 8-SEP-1999 17:11:51
Acquired: 04-MAR-1999 10:11:00



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GENERATED BY: DPELLEY	CHECKED BY:	APPROVED BY:

Figure 1 WCNLS4_001

```
Analysis Date/Time =  8-SEP-1999 17:13:41
Acquired Date/Time = 04-MAR-1999 12:35:09
Input File         =  CH_S1
Output File        =  WBNLR4_001
Number of Samples  =  7311
Segment Start Time =  77.360 seconds
Segment End Time   =  223.56 seconds
```

Description	Unit	Min	Max	Mean	S.D.	Chan
Carriage Speed	m/s	-0.0079393	0.091671	0.046410	0.013878	1
Wave Height	m	-0.13166	0.13943	0.00073273	0.086554	2
SURGE	m	-1.2426	0.52038	-0.65744	0.47125	3
SWAY	m	0.26981	1.4795	0.97608	0.35972	4
HEAVE	m	-0.022823	0.20409	0.095097	0.066337	5
YAW	deg	-175.38	175.78	91.581	130.92	6
PITCH	deg	6.5498	12.501	9.6268	1.6607	7
ROLL	deg	2.9905	4.1893	3.5057	0.17962	8
RMS	volts	0.65845	2.5994	1.5656	0.19357	9

SWIM Preliminary Experiments
Regular Wave Tests

NRC - IMD

Analyzed: 8-SEP-1999 17:13:41
Acquired: 04-MAR-1999 12:35:09

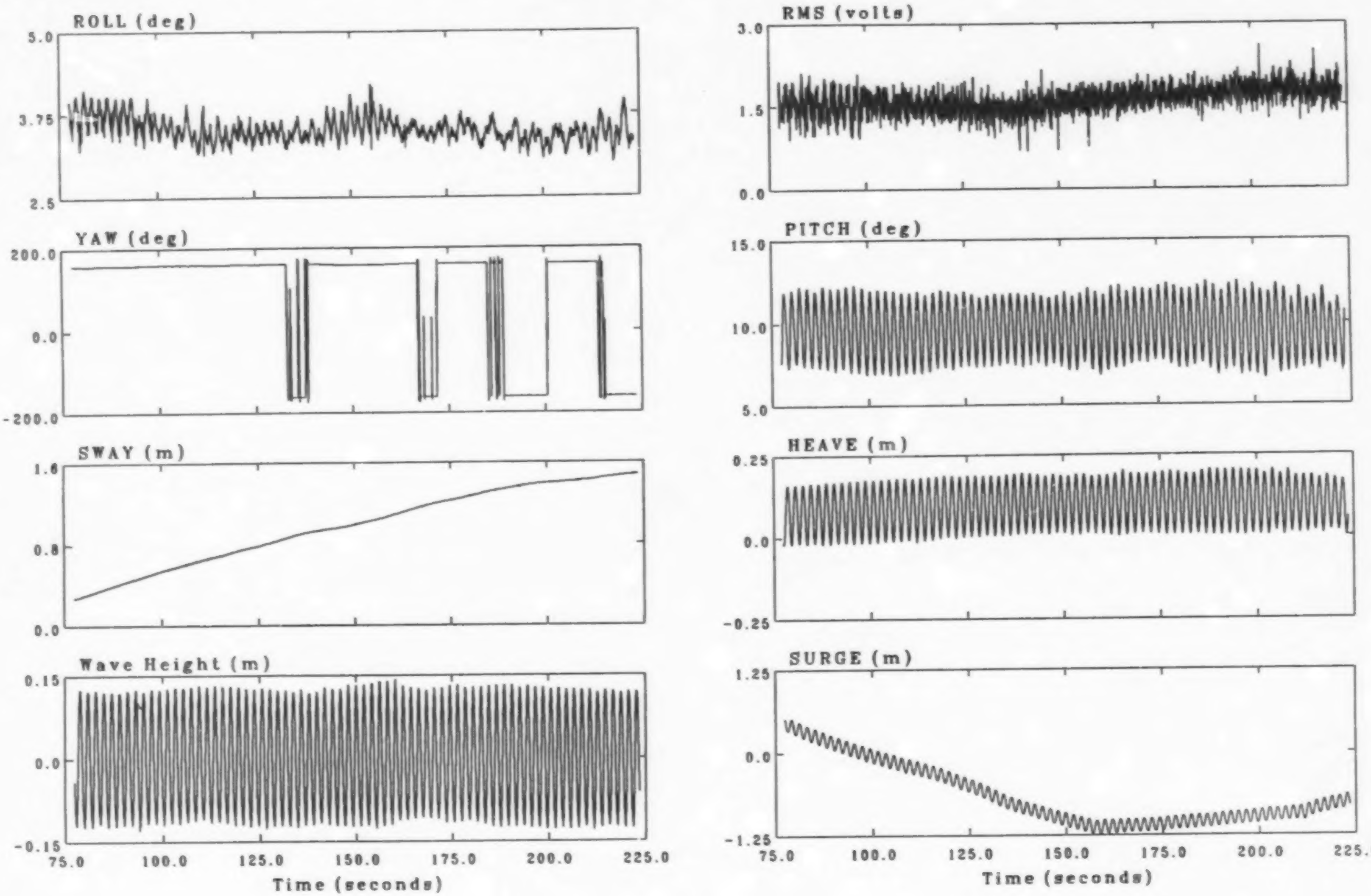

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Figure 1 WBNLR4_001

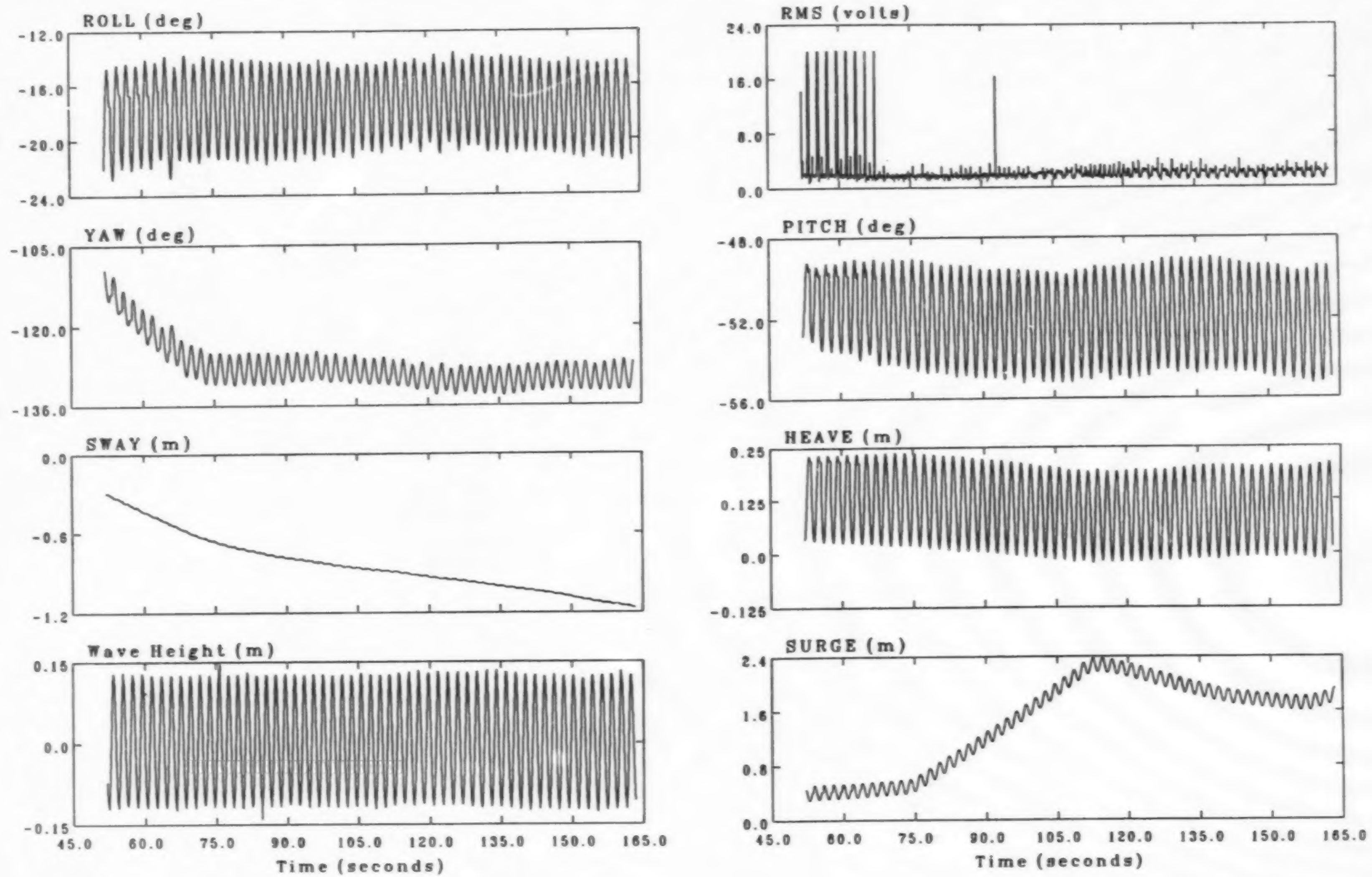
```
Analysis Date/Time =  8-SEP-1999 17:16:27
Acquired Date/Time = 04-MAR-1999 15:10:35
Input File         =  CH_S1
Output File        =  WBNJU_001
Number of Samples  =  5566
Segment Start Time =  52.080 seconds
Segment End Time   =  163.38 seconds
```

Description	Unit	Min	Max	Mean	S.D.	Chan
Carriage Speed	m/s	-0.016104	0.14393	0.032901	0.026205	1
Wave Height	m	-0.14163	0.14608	0.00057427	0.085362	2
SURGE	m	0.29336	2.3730	1.4370	0.65159	3
SWAY	m	-1.1680	-0.29681	-0.83835	0.21802	4
HEAVE	m	-0.022823	0.23782	0.10802	0.077941	5
YAW	deg	-133.16	-109.38	-127.65	4.2691	6
PITCH	deg	-55.340	-49.005	-51.955	1.9258	7
ROLL	deg	-22.834	-13.694	-17.581	2.4139	8
RMS	volts	0.67677	20.063	2.2070	2.3110	9

SWIM Preliminary Experiments
Regular Wave Tests

NRC - IMD

Analyzed: 8-SEP-1999 17:16:27
Acquired: 04-MAR-1999 15:10:35



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GENERATED BY: DPELLEY	CHECKED BY:	APPROVED BY:

Figure 1 WBNJU_001

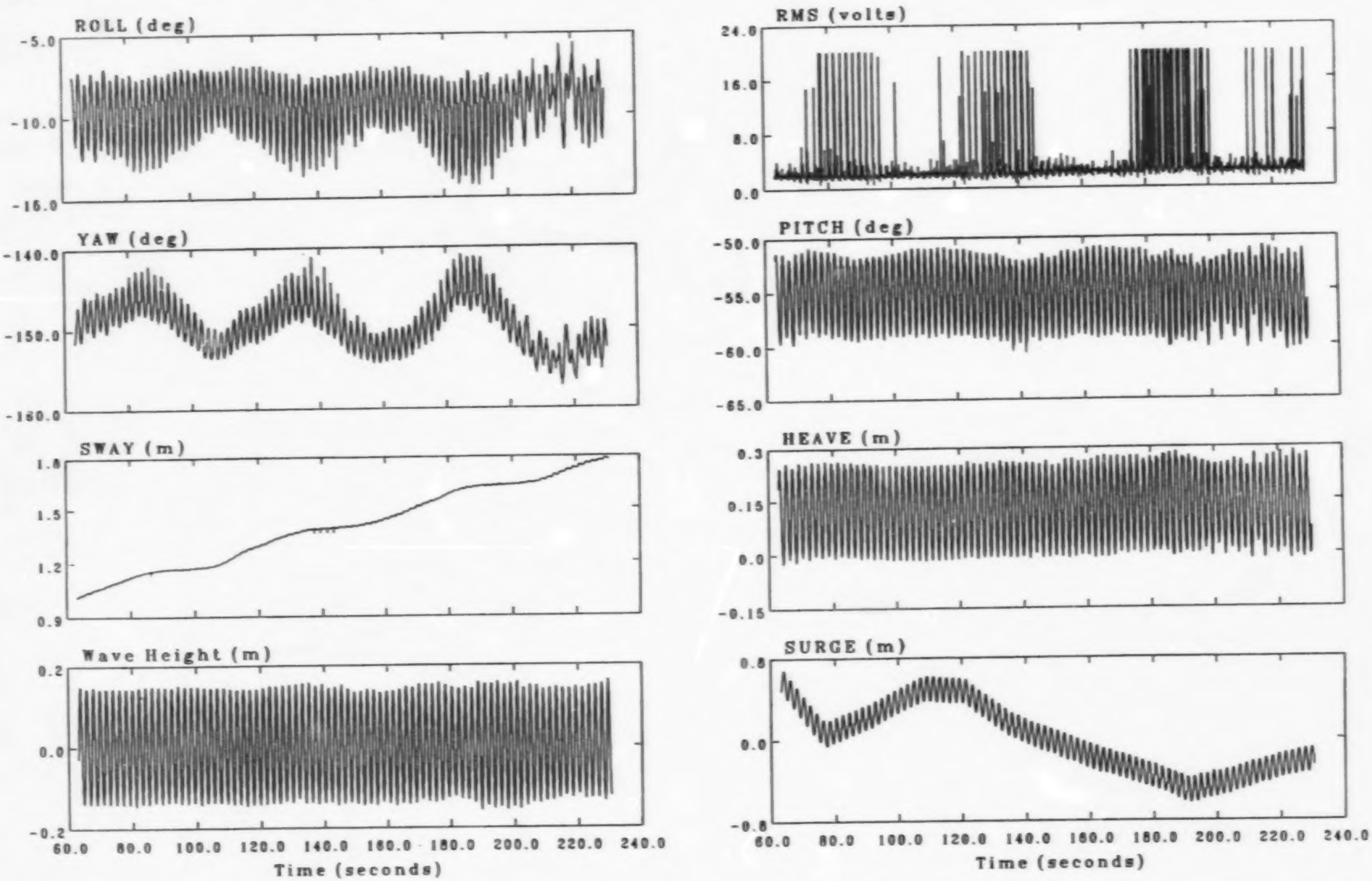
```
Analysis Date/Time =  8-SEP-1999 17:17:16
Acquired Date/Time = 04-MAR-1999 15:38:51
Input File         =  CH_S1
Output File        =  WBNJU_002
Number of Samples  =  8366
Segment Start Time =  63.040 seconds
Segment End Time   =  230.34 seconds
```

Description	Unit	Min	Max	Mean	S.D.	Chan
Carriage Speed	m/s	0.027986	0.13903	0.074927	0.014675	1
Wave Height	m	-0.15641	0.16012	0.00056229	0.099706	2
SURGE	m	-0.63045	0.68272	-0.0091549	0.34109	3
SWAY	m	1.0095	1.7880	1.4052	0.21721	4
HEAVE	m	-0.026122	0.28731	0.13181	0.097938	5
YAW	deg	-157.28	-141.02	-149.41	3.0057	6
PITCH	deg	-60.643	-50.839	-55.151	2.8456	7
ROLL	deg	-14.332	-5.5885	-9.4814	1.6698	8
RMS	volts	0.46966	20.063	3.4756	4.2357	9

SWIM Preliminary Experiments
Regular Wave Tests

NRC - IMD

Analyzed: 8-SEP-1999 17:17:16
Acquired: 04-MAR-1999 15:38:51



National Research Council Canada Institute for Marine Dynamics	GENERATED BY: DPELLEY	CHECKED BY:	APPROVED BY:
	Figure 1 WBNJU_002		

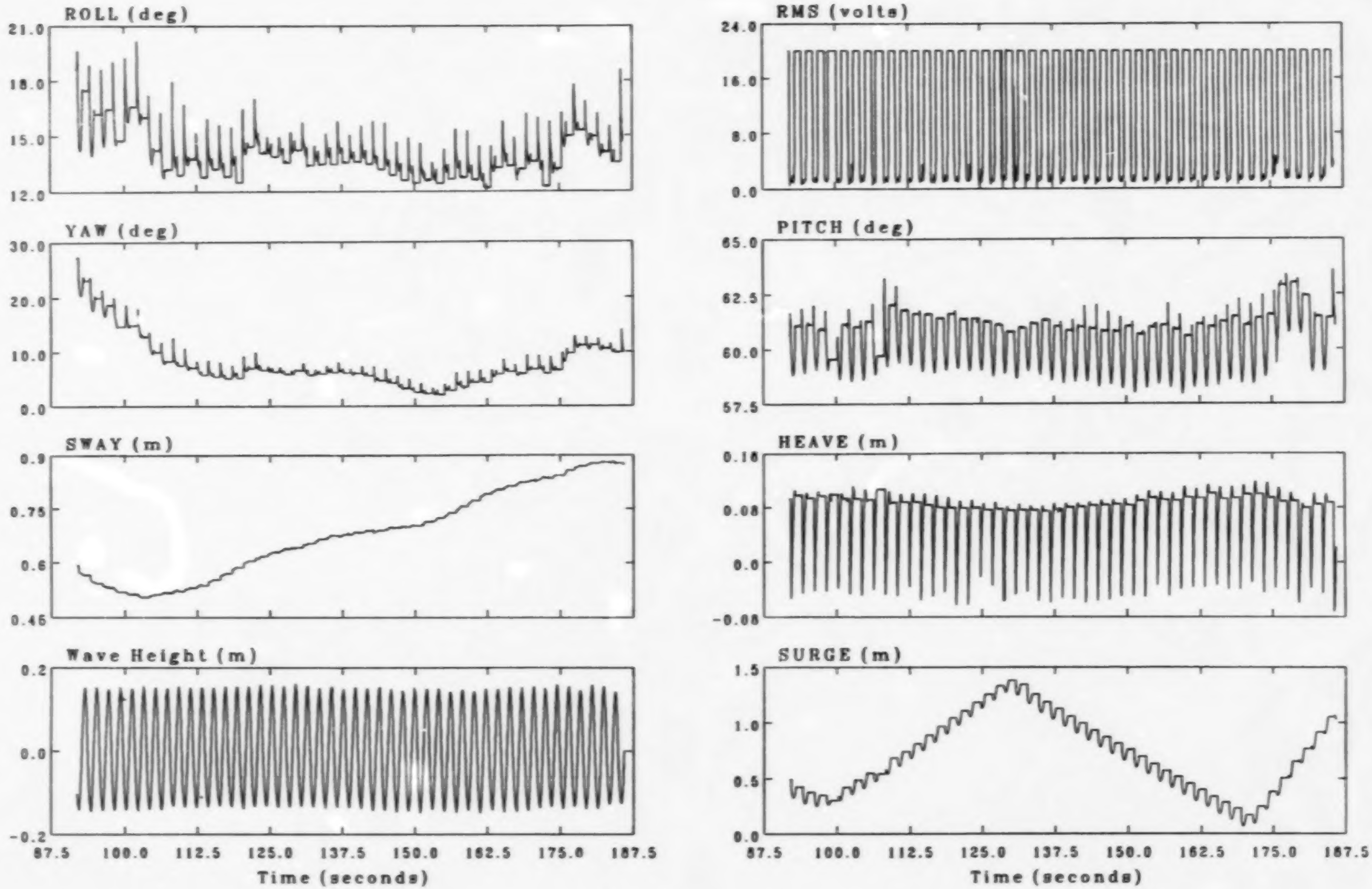
```
Analysis Date/Time =  8-SEP-1999 17:18:06
Acquired Date/Time = 04-MAR-1999 16:13:45
Input File         =  CH_S1
Output File        =  WBNJU_003
Number of Samples  =  4706
Segment Start Time =  91.880 seconds
Segment End Time   =  185.98 seconds
```

Description	Unit	Min	Max	Mean	S.D.	Chan
Carriage Speed	m/s	-0.022636	0.12106	0.046530	0.034724	1
Wave Height	m	-0.14754	0.16086	-0.00088967	0.10139	2
SURGE	m	0.064700	1.3812	0.70675	0.34401	3
SWAY	m	0.50398	0.88301	0.67980	0.11969	4
HEAVE	m	-0.072495	0.11740	0.072897	0.036696	5
YAW	deg	1.8657	27.340	7.8891	4.5430	6
PITCH	deg	57.911	63.609	60.602	1.0871	7
ROLL	deg	12.174	20.181	13.981	1.2280	8
RMS	volts	0.076827	20.063	12.058	9.0055	9

SWIM Preliminary Experiments
Regular Wave Tests

NRC - IMD

Analyzed: 8-SEP-1999 17:18:06
Acquired: 04-MAR-1999 16:13:45



National Research Council Canada Institute for Marine Dynamics	GENERATED BY: DPELLEY	CHECKED BY:	APPROVED BY:
	Figure 1 WBNJU_003		

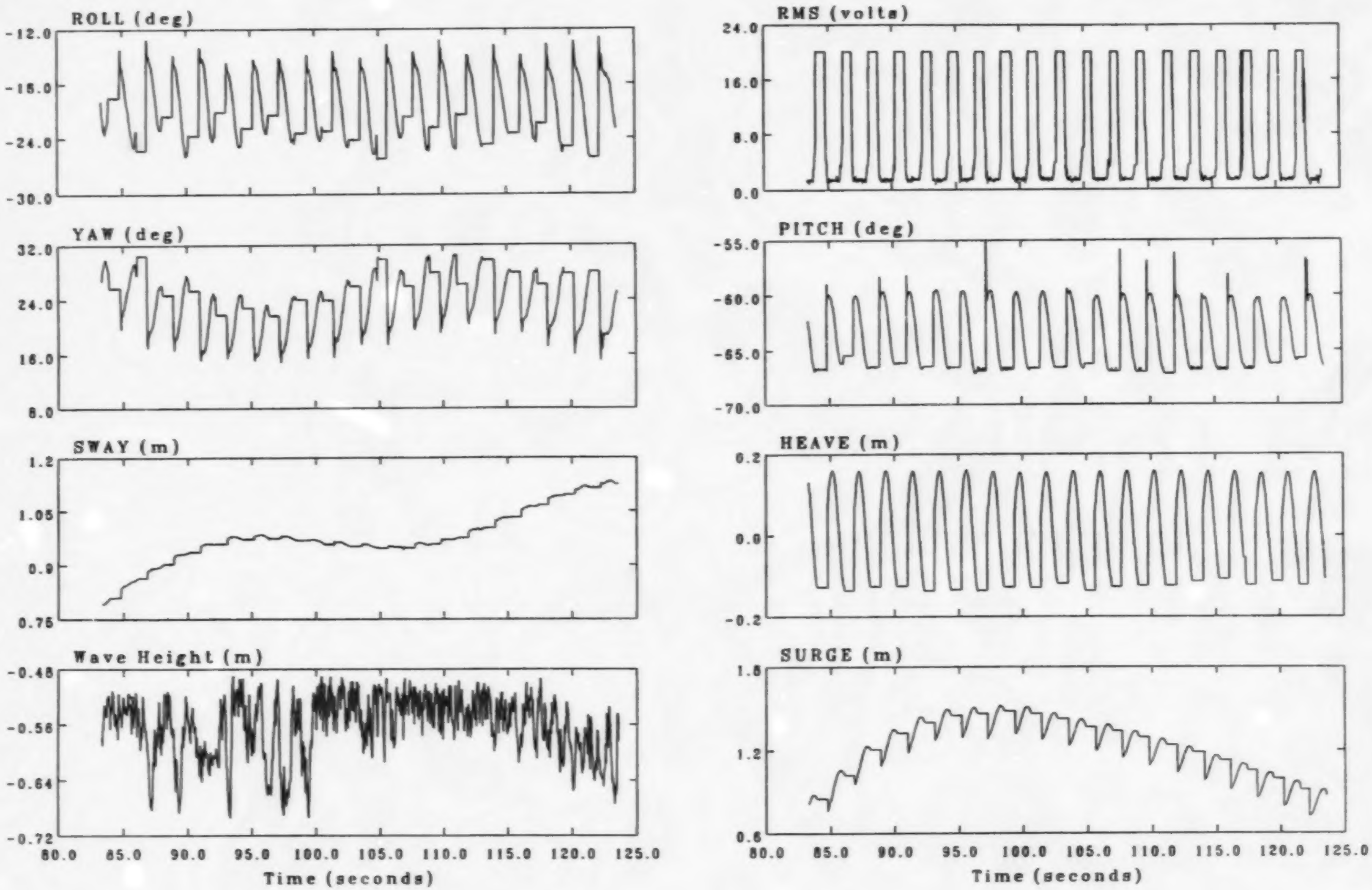
```
Analysis Date/Time =  8-SEP-1999 17:19:52
Acquired Date/Time = 03-MAR-1999 16:15:13
Input File         =  CH_S1
Output File        =  WBLJLS3_001
Number of Samples  =  2014
Segment Start Time =  83.340 seconds
Segment End Time   =  123.60 seconds
```

Description	Unit	Min	Max	Mean	S.D.	Chan
Carriage Speed	m/s	0.036151	0.19618	0.13512	0.041407	1
Wave Height	m	-0.69478	-0.49128	-0.56261	0.043613	2
SURGE	m	0.71954	1.5184	1.2156	0.20515	3
SWAY	m	0.79096	1.1328	0.97783	0.073142	4
HEAVE	m	-0.13793	0.15992	-0.0098070	0.11455	5
YAW	deg	14.932	30.615	24.019	3.7907	6
PITCH	deg	-67.187	-55.044	-64.162	2.8043	7
ROLL	deg	-26.288	-12.914	-21.079	3.2904	8
RMS	volts	0.53320	20.063	8.1364	8.5114	9

SWIM Preliminary Experiments
Regular Wave Tests

NRC - IMD

Analyzed: 8-SEP-1999 17:19:52
Acquired: 03-MAR-1999 16:15:13



National Research Council Canada Institute for Marine Dynamics	GENERATED BY: DPELLEY	CHECKED BY:	APPROVED BY:
	Figure 1 WBLJLS3_001		

```
Analysis Date/Time =  9-SEP-1999 10:11:36
Acquired Date/Time = 04-MAR-1999 09:56:36
Input File         =  CH_S1
Output File        =  WBNLS4_001
Number of Samples  =  9996
Segment Start Time =  92.280 seconds
Segment End Time   =  292.18 seconds
```

Description	Unit	Min	Max	Mean	S.D.	Chan
Carriage Speed	m/s	-0.011205	0.047581	0.014460	0.010953	1
Wave Height	m	-0.14976	0.14608	0.0035429	0.086652	2
SURGE	m	0.11215	2.1683	1.3627	0.50792	3
SWAY	m	-1.2863	-0.68024	-0.90986	0.15800	4
HEAVE	m	-0.031071	0.24368	0.13626	0.070025	5
YAW	deg	-150.44	-132.63	-141.90	5.1281	6
PITCH	deg	-27.585	-14.948	-20.900	3.1565	7
ROLL	deg	-12.386	-6.5124	-8.5216	1.4778	8
RMS	volts	0.37497	4.8514	1.7294	0.45587	9

SWIM Preliminary Experiments
Regular Wave Tests

NRC - IMD

Analyzed: 9-SEP-1999 10:11:36
Acquired: 04-MAR-1999 09:56:36

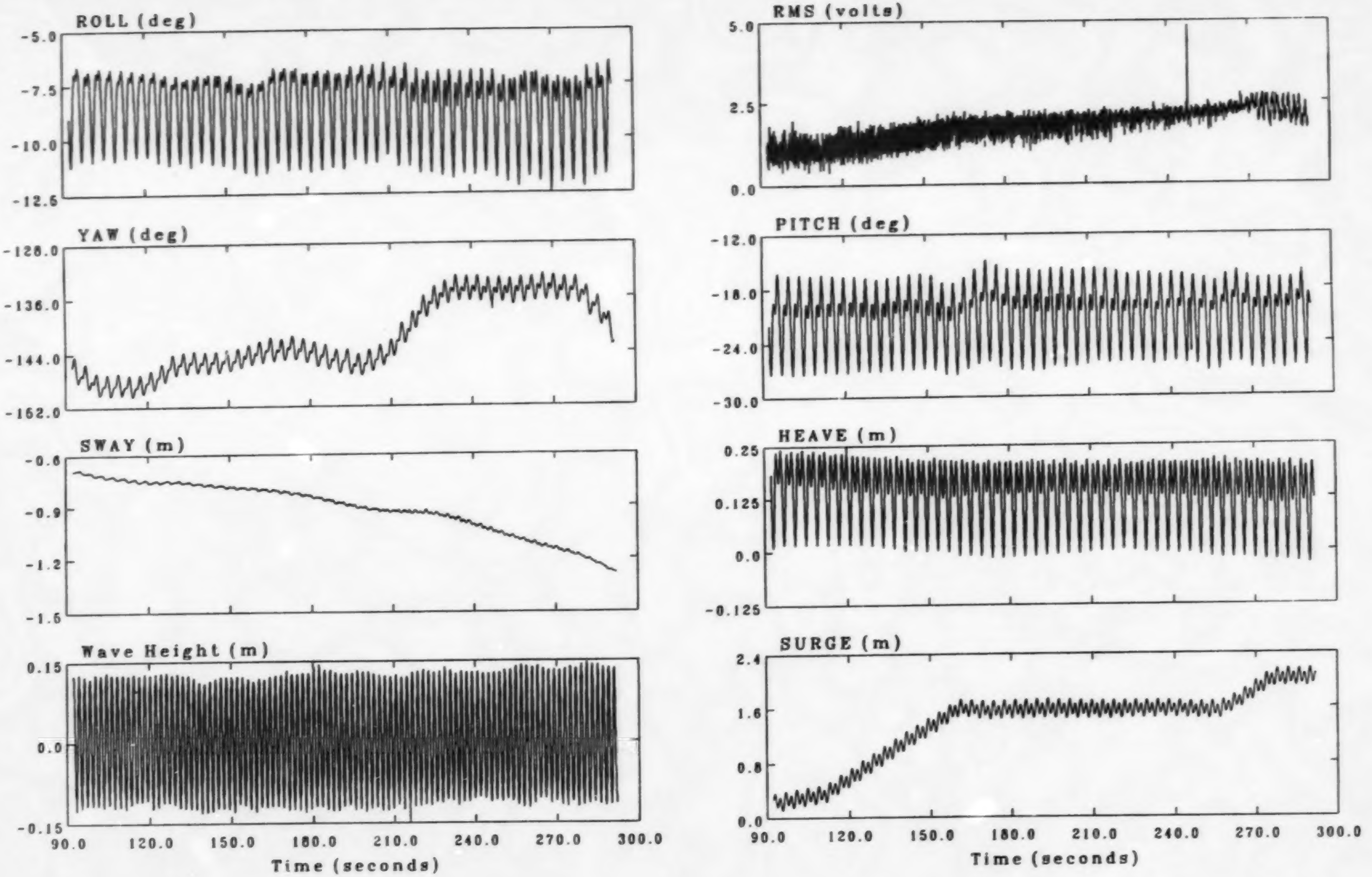


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Figure 1 WBNLS4_001

Analysis Date/Time = 9-SEP-1999 10:12:27
Acquired Date/Time = 04-MAR-1999 10:24:50
Input File = CH_S1
Output File = WCNLS4_002
Number of Samples = 6183
Segment Start Time = 46.980 seconds
Segment End Time = 170.62 seconds

Description	Unit	Min	Max	Mean	S.D.	Chan
Carriage Speed	m/s	-0.016104	0.078607	0.028612	0.0052329	1
Wave Height	m	-0.13757	0.17563	0.0016763	0.084489	2
SURGE	m	-0.049266	0.72944	0.45724	0.20410	3
SWAY	m	-1.1673	0.21755	-0.49632	0.40568	4
HEAVE	m	0.086236	0.22261	0.14947	0.035331	5
YAW	deg	-139.45	-120.93	-130.37	4.0714	6
PITCH	deg	-19.109	-7.8440	-12.907	2.2362	7
ROLL	deg	-16.642	-6.4464	-11.796	1.6581	8
RMS	volts	0.34625	20.063	1.5065	1.0048	9

SWIM Preliminary Experiments
Regular Wave Tests

NRC - IMD

Analyzed: 9-SEP-1999 10:12:27
Acquired: 04-MAR-1999 10:24:50

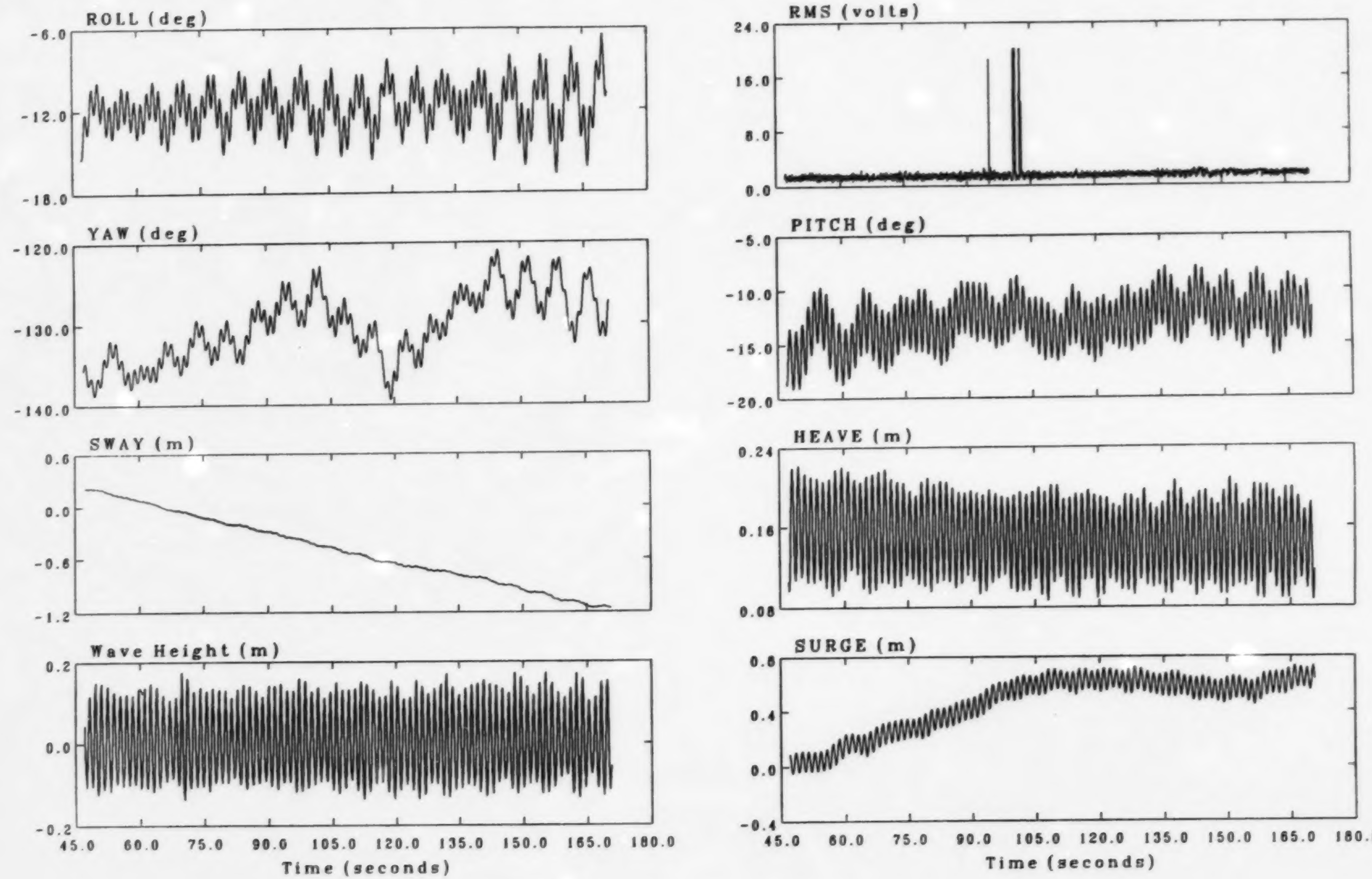

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Figure 1 WCNLS4_002

APPENDIX 7: SELECTED PHOTOGRAPHS OF SWIM DURING TESTING